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Factfile No. 10

The Society of Light and Lighting
Part of the Chartered Institution of Building Services Engineers

Providing visibility for an ageing workforce

1 The problem

Britain has an ageing workforce. This Factfile is devoted to what changes might be made to visual tasks, lighting systems and décor to offset the changes in the human visual system that occur with age.

2 Legislation

There are two pieces of legislation relevant to the lighting of workplaces for an ageing workforce: the Employment Equality (Age) Regulations 2006 and the Disability Discrimination Act 1995.

As a result of EU Directive 2000/78/EC, the British Government is introducing the Employment Equality (Age) Regulations on 1 October 2006. These regulations introduce a default retirement age of 65 years for men and women. Compulsory retirement ages less than 65 years become illegal. Further, all workers will have the right to request to continue working beyond 65 years and companies will have a duty to consider such a request. In addition to these changes related to retirement, the regulations prohibit all harassment and victimisation on the grounds of age.

These regulations apply to all workers with the exception of members of the armed forces and unpaid volunteers. There is also an exemption on the basis of a genuine occupational requirement. The purpose of these regulations is to eliminate discrimination against older people in employment and training. If successful, they will increase the employment opportunities of older people and lead to an increase in the numbers of older people in the workforce.

The Disability Discrimination Act 1995 requires the modification of premises to facilitate their use by disabled workers and customers. There are many forms of disability but it is partial sight that is of interest for lighting practice. The incidence of partial sight increases dramatically with increasing age. This suggests that if, as a result of the Employment Equality (Age) Regulations 2006, many more people continue working after 65 years, the percentage of the working population with visual difficulties will increase.

3 The ageing of the visual system

3.1 Changes in the eye with age

The human visual system consists of the eye and brain working together. Figure 1 shows a section through the eye, the upper and lower halves being adjusted for focus at near and far distances, respectively. Light reaching the eye is first refracted at the air/cornea surface, then passes through the pupil, is refracted again at the lens and finally reaches the retina. At the retina, light is absorbed by the photoreceptors and converted into electrical signals. These signals are processed in the retina and then transmitted up the optic nerve to the visual cortex of the brain where they are interpreted to create a model of the outside world.

The human visual system can be considered as an image-processing system. Like all such systems, it is most effective when it is operating at

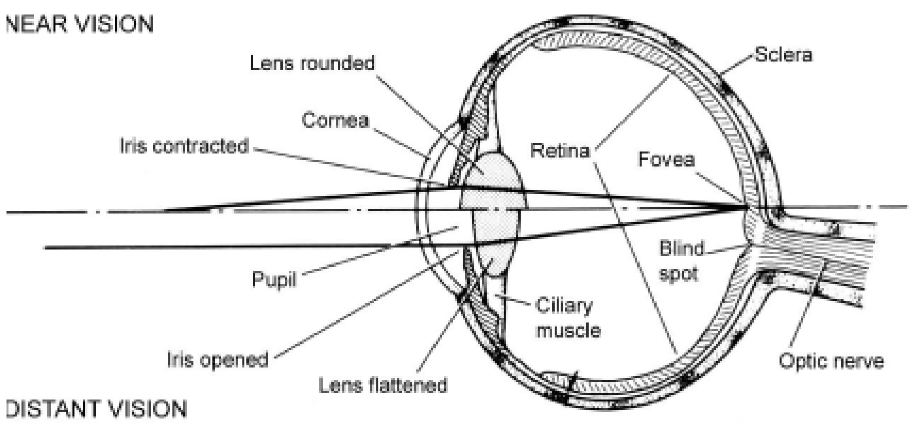


Figure 1. A section through the eye adjusted for near and distant vision.

an appropriate sensitivity with a clear retinal image to process. The factors that determine the operating state of the visual system are the amount of light that reaches the retina and the wavelengths from which it is constituted. The factors that determine the clarity of the retinal image are the ability to focus the image of the external object on the retina; the extent to which light is forward scattered as it passes through the eye; and the presence of stray light. Virtually all these characteristics change with age.

The optical factors determining the amount of light reaching the retina are the pupil size and the spectral absorption of the components of the eye. The area of the pupil varies as the amount of light available changes, the pupil opening to admit more light when there is little and closing when there is plenty. The ratio of maximum to minimum pupil area decreases with age, the maximum decreasing much more than the minimum. This means the elderly are much less able than young people to compensate for low light levels by opening their pupils.

The absorbance of the human lens increases exponentially with increasing age, particularly at short wavelengths. The causes of this increased absorbance with age are changes that occur primarily in the nucleus of the lens. This implies that the spectral absorbance of the lens will also vary with pupil size, smaller pupil sizes leading to greater absorbance.

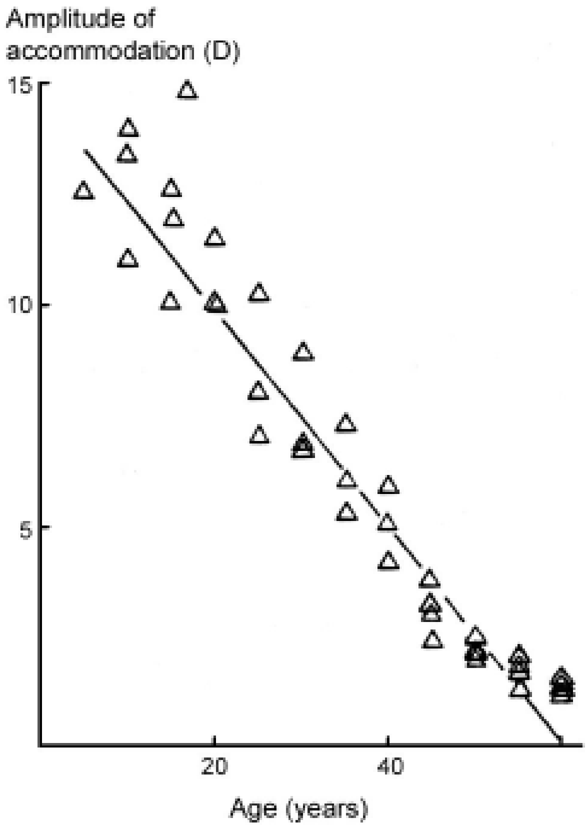


Figure 2. The variation of the amplitude of accommodation with age. The amplitude of accommodation is measured in dioptres, the difference between the reciprocals of the shortest and longest distances from the eye at which a sharp retinal image can be achieved, the distances being measured in metres (after Weale, 1990).[1]

Taken together, the reduction in pupil size and the increased absorption of light during its passage through the lens serve dramatically to reduce the retinal illumination of older people, particularly at short wavelengths. For example, it has been estimated that, for the same illuminance striking the cornea, a 20 year old will receive three times the amount of light at the retina that a 60 year old will receive.

To bring the image of objects at different distances into focus on the retina, the optical power of the eye has to change. The optical power of the eye is determined by the curvature of the cornea, which is fixed, and the thickness of the lens, which is variable. The range of object distances that can be brought to focus on the retina decreases with age, because of increasing rigidity of the lens. After about 60 years of age, the eye is virtually a fixed focus optical system (Figure 2). Spectacles or contact lenses are used to modify the optical power of the eye, the prescription of the spectacles or contact lens changing over the years as the lens becomes increasingly rigid.

Another cause of a blurred retinal image is the scattering of light. Scattered light degrades the retinal image by reducing the difference in luminance either side of an edge. Scattered light also degrades the retinal image in terms of colour by adding wavelengths from one area onto another, thereby reducing the colour difference at the edge. The scattering occurring in the eye is primarily large-particle scattering, so is largely independent of wavelength. The amount of scatter increases with age, due mainly to changes in the lens.

Another factor determining the quality of the retinal image is the amount of straylight in the eye. Straylight matters because it falls uniformly across the retinal image, thereby reducing the luminance contrast of all edges and the saturation of all colours in the image. Straylight is caused by light back-reflected from the retina, by transmission of light through the iris and the eye-wall, and by lens fluorescence. The amount of straylight generated by these causes increases with age.

3.2 Changes in the retina and visual cortex with age

The optical changes that occur with age affect the retinal image, but for the visual system to be effective, the retinal image has to be processed by the retina and the visual cortex. Ageing is not limited to the optical elements of the visual system. Morphological changes have been reported in the retinal rod and cone photoreceptors with age, and in the density of these photoreceptors, in the number of ganglion cells in the retina and in the number of neurons in the visual cortex, all of which decrease with increasing age. The fact that the neural elements of the visual system also show changes with age implies that the compensation for visual-system ageing that can be provided by lighting is inevitably limited. Returning the optical characteristics of the eye to what they were before ageing will not restore vision to its pristine state.

3.3 Partial sight

Both the optical and neural changes discussed above are part of the normal process of ageing. Everyone who lives long enough will experience these changes, but with increasing age there is also an increased probability of pathological change occurring in the eye. These pathological changes can lead to partial sight and, ultimately, blindness. The definitions of these conditions used to determine entry to the Blind and Partially Sighted Register in the UK are given in Table 1.

This classification system uses the visual acuity of the better eye, with optical correction, and the size of the visual field to assess suitability for registration. In these criteria, visual acuity is expressed as the ratio of two distances, e.g. 3/60. The numerator refers to the distance, in metres, from which the person being tested looks at a test chart and determines the smallest size of target where the detail can be resolved, e.g., a letter can be correctly identified (in this case 3 m). The denominator is the distance, in metres, at which a person with normal vision can be expected to resolve the same detail (in this case 60 m).

Table 1. Criteria for inclusion in the Blind and Partially Sighted Register in the UK

Blindness	Partial Sight
Visual acuity less than 3/60	Visual acuity between 3/60 and 6/60 with a full visual field
or	or
Visual acuity more than 6/60 but with very constricted visual field	Visual acuity 6/24 or worse with a moderate constriction of the visual field
or	or
Visual acuity 6/60 or above with very constricted visual field especially in the lower part of the field	Visual acuity 6/18 or better with gross visual field distortion

Table 2 shows the relative incidence of different causes of partial sight based on an analysis of the people in England and Wales registered as partially sighted in the period April 1999 to March 2000. The most common causes of registered partial sight are macular degeneration, glaucoma and diabetic retinopathy. Cataract is common in practice but rare as a reason for being registered for partial sight because it is treatable. In fact, about half of the patients seen by ophthalmologists for possible partial sight can have their sight improved markedly by better optical correction or by cataract removal.

Table 2. Percentage of people registered as partially sighted in one year in England and Wales, for different causes (Bunce and Wormald, 2006).[2]

Cause	Percentage
Macular degeneration	56.0
Glaucoma	10.2
Diabetic retinopathy	7.4
Cerebrovascular disease	4.9
Retinal vascular occlusion	2.0
Hereditary retinal disorder	2.0
Optic atrophy	1.9
Myopia	1.9
Cataract	1.5
Multiple pathology	3.2
Others	8.5
Unknown	0.5

Table 3 shows the incidence per 100,000 population of registration for blindness and partial sight, for different causes, in one year, in England and Wales, by age. It is clear that the incidence of all three of the major causes of registered partial sight increase dramatically with age.

Macular degeneration is shown by changes in the appearance of the macular of the retina. The macular is a circular area superimposed over the fovea, the area of the retina used to see detail. This implies a serious decline in central vision, ultimately making such everyday activities as reading and seeing faces impossible. Figure 3 simulates how a scene might appear to a person with macular degeneration

Glaucoma is shown by progressive visual field

Table 3. Incidence per 100,000 population of different causes of registration for blindness and partial sight, in one year, in England and Wales, by age (Bunce and Wormald, 2006).[2]

Age range	Macular degeneration	Glaucoma retinopathy	Diabetic
0 to 15 years	0.01	0.05	0.05
16 to 64 years	1.01	0.55	2.05
65 to 74 years	39.69	9.96	15.06
75 to 84 years	251.53	44.14	17.08
85 years +	699.62	113.62	11.02

Normal vision

Cataract

Macular degeneration

Diabetic retinopathy

Glaucoma

Figure 3. An illustration of a scene as it might appear to people with normal vision and with cataract, macular degeneration, diabetic retinopathy and glaucoma (from the National Eye Institute, National Institutes of Health)

loss (Figure 3), leading ultimately to blindness. As glaucoma develops it leads to reduced contrast sensitivity, poor night vision and slowed transient adaptation but the resolution of detail seen on-axis is unaffected until the final stage.

Diabetic retinopathy effectively destroys parts of the retina through the changes it produces in the vascular system supplying the retina. The effect these changes have on visual capabilities depends on where the damage occurs and the rate at which it progresses (Figure 3).

Cataract is an opacity developing in the lens. The effect of cataract is to absorb and scatter more light as the light passes through the lens. This increased absorption and scattering results in reduced visual acuity and reduced contrast sensitivity over the entire visual field, as well as diminished colour discrimination and greater sensitivity to glare (Figure 3).

4 The effect of ageing on visual capabilities

The effect of increasing age on visual capabilities is almost always negative. Specifically, older people tend to show reduced visual field size, increased absolute threshold luminance, reduced visual acuity and poorer colour discrimination.

Figure 4 shows visual acuity plotted against age. The trend with age is consistent: increasing age leads to worse visual acuity.

Figure 5 shows the threshold contrast achieved by different people of different ages at different luminances. These results demonstrate the expected increase in threshold contrast with decreasing adaptation luminance but there is also a trend of increasing threshold contrast with increasing age, at all three adaptation luminances.

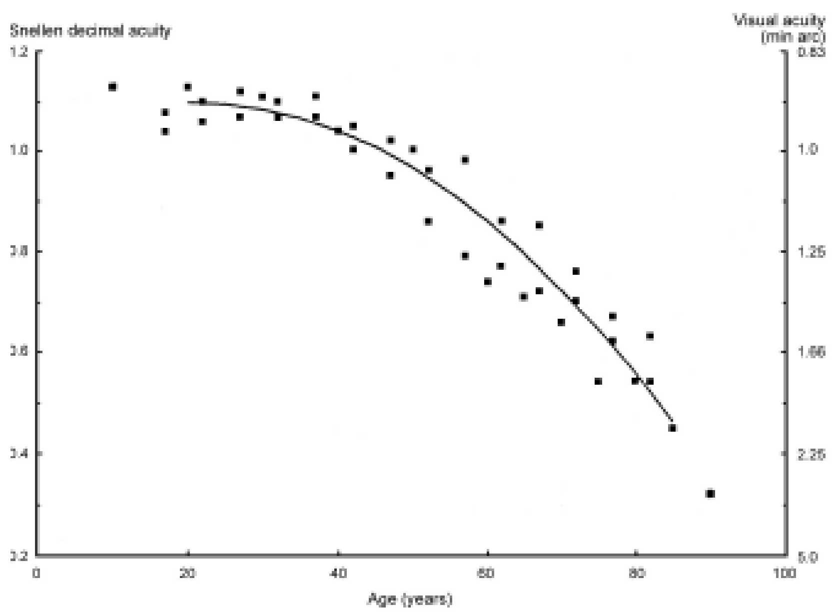


Figure 4. Visual acuity, expressed as Snellen decimals and as angle subtended, as a function of age (after Adrian, 1995).[3]

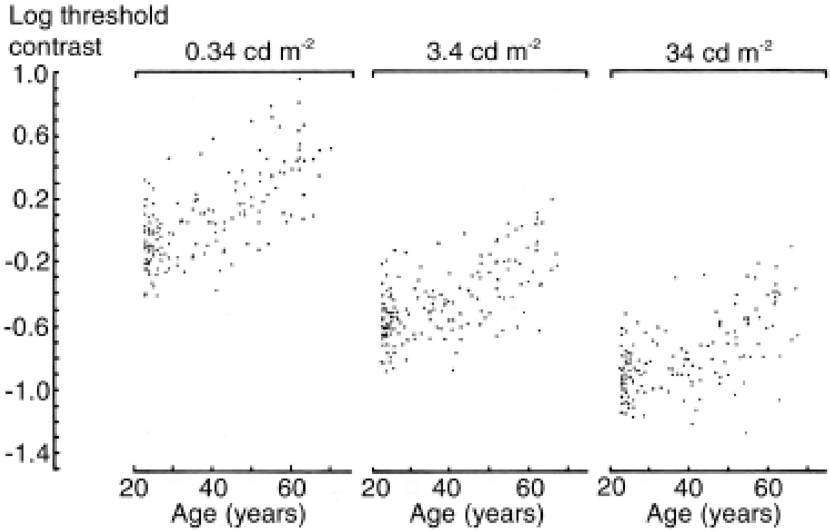


Figure 5. Log threshold contrasts for individuals of different ages at three different background luminances (after Blackwell and Blackwell, 1971)[4]

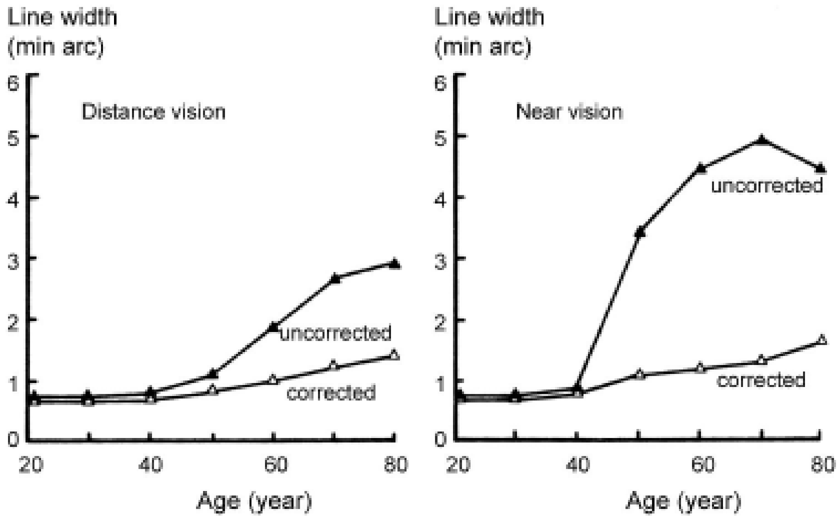


Figure 6. Subtended line widths of letters that can just be read by 50 percent of observers, for distant and near vision, with and without their usual spectacles, plotted against age, For distant vision, the test letters were 6m from the observer while for near vision, they were 0.36 m from the observer (after US Department of Health, Education and Welfare, 1962)[5]

While the deterioration in visual function with age is evident in all these aspects of threshold performance, there are two other general conclusions that deserve emphasis. The first is that the deterioration in visual capabilities with age starts in early adulthood and continues at an accelerating rate as the years pass. The second is that there are wide individual differences in visual function, sometimes wide enough to overcome the effects of age.

The worsening of visual capabilities with age has implications for the performance of many real tasks. Kosnik *et al*. (1988)[6] identified five types of generic visual problems that increase in difficulty with age. They were seeing in dim light, reading small print, distinguishing dark colours, reading moving information and visual search.

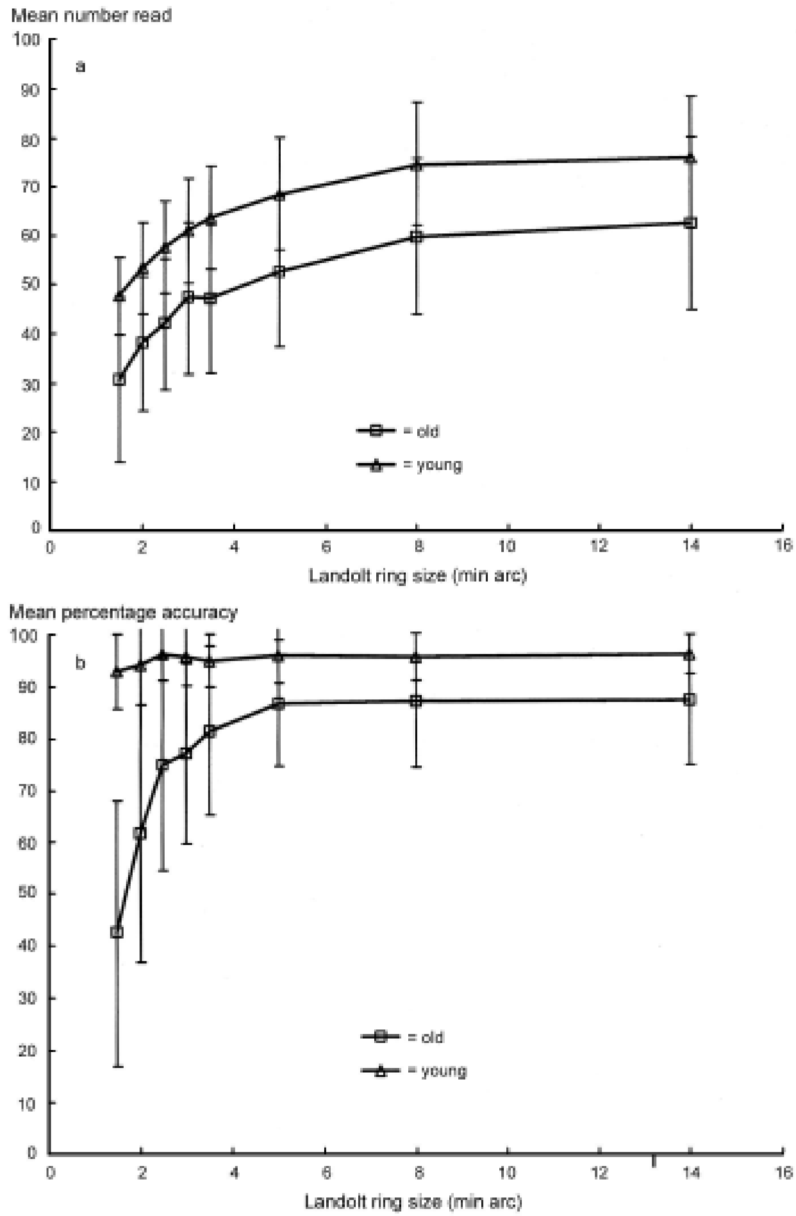
5 Compensating for visual changes with age

There are three approaches to offsetting some or all of the effects of age on visual capabilities. They are to change the optics of the eye so as to provide a sharper retinal image of the task; change the task so that the stimuli it presents are higher above threshold; change the lighting to enhance the capabilities of the visual system or to move the stimuli presented by the task higher above threshold.

5.1 Changing the optics

The first and most widely experienced effect of aging on the visual system is the increase in the closest distance at which an image can be focused on the retina, the near point. Eventually, the near point moves so far away that it is no longer possible to read a newspaper, even when held at arms' length. This problem can be overcome by the use of spectacles or contact lenses with the appropriate optical power. Figure 6 shows the effect of wearing spectacles on visual acuity, for near and distance vision, for people of different ages. Wearing spectacles to bring the retinal image into focus produces a marked improvement in visual acuity for older people, although it does not completely restore visual acuity to what is was when young because sim-

Figure 7. Speed and accuracy of performance of a high-contrast Landolt ring task, plotted against Landolt ring gap size measured in angular subtense at the eye, for two age groups (18–28 years and 61–78 years). The error bars are standard deviations (after Boyce et al., 2002).[7]



ply wearing spectacles does nothing to offset the other optical and neural changes that occur in the eye with age.

The other reason why the optics of the eye are sometimes changed is the development of cataract. Today it is routine to replace a cataracterous lens with a plastic lens of fixed optical power. Removing a cataract certainly reduces light absorption, light scatter and lens fluorescence. For many people, removing a cataract will markedly improve visual acuity and contrast sensitivity and will enhance the saturation of colours

5.2 Changing the task

Figure 7 shows the speed and accuracy of identifying gaps of a particular orientation in an array of Landolt rings, for two age groups. Increasing the size of the gap in the Landolt ring leads to greater speed and higher accuracy until saturation in performance occurs for both age groups. However, the effects of increasing size are more marked for the older age group, particularly for accuracy when the gap size is small. Figure 7 also shows that enhancing the visual stimulus will not bring the level of performance of the older subjects to that of the young subjects. Even at the largest print size, there is a difference in both speed and accuracy of performance between the two age groups.

The size of the retinal image of a task can be increased either by making the task bigger, e.g. large print books, or by bringing the task closer if focus can be maintained; or by using some form of magnification. Magnification can be achieved either optically or electronically, but both forms need to be optimised for the individual and the task. This is because the greater is the magnification, the smaller is the field of view. If the task involves some form of scanning, e.g., reading text, then optimisation of the magnification and field of view is essential.

Size is just one dimension that can be used to make a task easier to do. Another is luminance contrast. Increasing luminance contrast is a feature of much advice on how to make life easier for people with partial sight. For example, a high luminance contrast between floor and walls, and between walls and door will help a partially sighted person find the door and open it. While high luminance contrasts are undoubtedly useful, they should be attached only to salient aspects of the space. Too many different luminance contrasts produce a confusing picture for people with partial sight to interpret.

One way to maximise luminance contrast is to minimise the amount of scattered light in the eye by reducing the luminance immediately surrounding the task. For print, a piece of black card with a slot cut in it can be positioned over the page so that only a few lines of print can be seen at a time. For a computer monitor, a display using bright letters on a dark background will be easier to read than the reverse, provided that reflections from the screen are controlled.

Colour can be used to enhance visual performance in three different ways. The first is to identify objects. It has been found that colour improves the recognition of images of familiar foods by people with normal vision and partial sight. The second is to make items more conspicuous. The third is as a substitute for luminance contrast. In the absence of luminance contrast, a colour difference between the task and its immediate background is the only way in which the task can be seen.

5.3 Changing the lighting

The characteristics of lighting that can produce an improvement in visual performance are the amount of light, the spectrum of the light and the spatial distribution of light.

Increasing retinal illuminance will lead to an improvement in visual performance, although the magnitude of the improvement will vary with the separation of the size and contrast of the task from their respective threshold values; the greater the separation, the less the impact of increasing the retinal illuminance.

The spectrum of light is important for colour discrimination. It is much easier to discriminate colours that are widely separated in colour space than those that are close together. The extent to which a light source will separate colours in colour space is positively correlated to its Colour Rendering Index.

As for the distribution of light, it is desirable that the light be uniformly distributed on all the relevant surfaces, without casting shadows. In a room, the factors that determine illuminance uniformity are the spacing between luminaires and the reflectances of the room surfaces. Where uniform lighting is required, the maximum spacing between luminaires recommended by the manufacturer should not be exceeded. As for surface reflectances, a uniform distribution of light is much easier to achieve with high room surface reflectances.

Light distribution is particularly important when self-luminous displays are used. The lighting in a room makes self-luminous displays less visible in two ways. First, ambient light reflected from the screen reduces the luminance contrast andly desaturates the colours of the display. Second, light reflected from the specular front surface of the screen can produce an image of the room on the screen. If the room contains high luminance luminaires or windows, two alternative views of the world can be seen: one generated by the display, and the other by the specular reflection. In a small space, reflections from the screen can be avoided by careful positioning. In large spaces containing many screens, careful design is required (SLL, 2005).[8]

Another adverse aspect of light distribution is glare. The increased scattering of light in the eye that occurs with increasing age can be expected to produce increases in the level of discomfort and disability glare produced by a given lighting installation.

6 Checklist

The above discussion leads to a checklist of actions that can be taken to deal with the visual problems posed by an ageing workforce.

1. Ensure that all members of the workforce have an accurate optical correction for the work they do.

2. Increase the visual size, luminance contrast or colour contrast of what needs to be seen. It is usually be much more effective to make the task easier than to change the lighting.

3. Minimise veiling reflections and shadows in and around the work. Veiling reflections reduce contrast in task details. Shadows reduce the illuminance on the task and can cause confusion over details of the task. Veiling reflections can be eliminated by using only matt materials. Shadows can be reduced by using large-area luminaires. Both can be reduced by increasing

the amount of inter-reflected light.
4. If it is not possible to make what needs to be seen visually easier, enhance the lighting. This means:

- Using light sources with a Colour Rendering Index of more than 80
- Using luminaires that do not allow a view of the light source from common viewing directions, seen either directly or by reflection in a highly specular surface.
- For ambient lighting, the Unified Glare Rating (UGR) of the installation should be 19 or less.
- Provide adjustable blinds on windows that enable occupants to reduce window brightness, preferably while retaining some view out.
- For ambient lighting, increase the minimum maintained illuminance by 50% above that recommended for the work. In all situations where an ageing workforce is active, the minimum maintained illuminance should be at least 300 lx.
- For localised task lighting, provide a well-shielded, adjustable task light producing an illuminance of at least 1000 lx on the task. The adjustment should enable changes to be made in the amount and distribution of light.
- For ambient lighting, ensure the maximum spacing/mounting height ratio of the luminaire has not been exceeded to ensure a high level of illuminance uniformity.

5. As well as enhancing the lighting, it is also desirable to check that the décor

- Consists mainly of high reflectance matt surfaces
- Does not contain very specular surfaces in and around the task area
- Provides high contrast on salient detail in the space
- Minimises the degree of obstruction in the space

Following this advice will improve the visual capabilities for the elderly and for many people with partial sight without adversely affecting the young.

This advice has necessarily been general rather than specific. Specific advice on lighting appropriate for different activities undertaken by the elderly and by people with partial sight is given by both international and national lighting authorities (CIE, 1997; IESNA, 1998, SLL, 2004), by organisations devoted to the welfare of the elderly (Figueiro, 2001), and by knowledgeable individuals (Lewis, 1992).

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