Brien Holden Vision Institute

OCCUPATIONAL AND ENVIRONMENTAL VISION

- The Role of the Optometrist in Occupational Safety and Health -

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INTRODUCTION

Optometry has a long history of dealing with the problems of vision and eye safety in the workplace. Many occupational safety and industrial hygiene experts lack the necessary knowledge and skills to manage industrial sight conservation programmes. This is an introduction to the field of environmental vision and how the optometrist can provide eye safety services to industry.

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INTRODUCTION

Eye injuries comprise between 5 and 10% of the reported lost time that occur in the workplace. Many of these are preventable, being due to the inappropriate use or lack of use, of eye protectors. Those affected tend to be young and relatively inexperienced, or older experienced workers who have not followed established safety procedures.

Regardless of how an accidental eye injury occurs, it has substantial costs to the employee, employer and the health care system.

An injured employee can suffer loss of income while recovering from the injury. In some cases, the worker may become unemployable in his or her vocation, because of the decreased vision resulting from the injury.

There are also substantial costs to the employer. First, a replacement worker must be hired and trained. The expense of hiring and training may be wasted since these employees will be discharged upon the return of the injured worker. In addition, the premiums charged for public or private worker compensation plans may increase after employees are injured. Finally, there may be fines and legal costs arising from the investigation of the accidental injury, especially if it is proved that the employer or his agents failed to provide adequate safety instructions or equipment to the injured worker.

Society as a whole also pays for the injured worker. Tax revenues are spent on providing emergency care, hospitalisation, health care services, and costs of rehabilitation and retraining. In addition, the employer's costs related to the injury will be added to the prices of commodities or services sold to the public.

As a provider of primary eye care, the optometrist is uniquely positioned to provide the consulting, diagnostic and treatment services needed to establish and maintain an eye protection programme for a given workplace. By identifying hazardous situations in the workplace and analysing the visual demands of the workers' tasks, the optometrist can plan appropriate programmes to provide safety eyewear and to monitor the continued ocular health of the worker.

The components of an industrial Eye Protection Programme include:

- Workplace environment survey
- Vision screening
- Steps for implementation of the programme
- Steps for maintenance of the programme.

THE WORKPLACE SURVEY

A workplace survey is comprised of an analysis of ocular hazards present in the worker's environment, and an analysis of the ergonomic factors affecting vision. While it is neither cost effective nor necessary to make an on-site visit for every patient who requests occupational vision care, such a visit is mandatory when the practitioner is considering the establishment of an occupational vision plan with a large group of employees with many different tasks. By becoming familiar with the visual environments of the workers, the practitioner can provide services which are appropriate for their particular needs.

OCULO-VISUAL HAZARD ANALYSIS

An oculo-visual hazard analysis includes identification of all existing or potential ocular hazards, a review of existing safety policies, procedures and facilities, worker complaints, and recent accidental eye injury reports. Regulations made under occupational safety legislation often require that workers, supervisors, and designated safety personnel in the workplace be given information on hazardous materials and circumstances in the workplace. This information includes the nature of the hazard, allowed limits of worker exposure, safe handling procedures, and emergency measures. Selection of appropriate personal protective equipment will be dictated by this information.

Physical Hazards

Ocular hazards can be classified according to the scheme outlined in Table 1.

Table 1. *Ocular hazard classification*

Mechanical Hazards	Dust Particles Compression Hot solids
Non-mechanical Hazards	Chemical Thermal Radiation / radiant energy Electrical

The following review of eye hazards is not intended to be an exhaustive list, but rather a guide for the reader in identifying existing and potential hazards in the workplace.

Mechanical Hazards

Mechanical eye injuries comprise approximately 70 to 80% of all work-related eye injuries. The range of severity of these injuries is large because of the wide range of missile size, mass and speed that may be involved.

Large slow-moving missiles cause contusive or concussive injuries to the eye and adnexa. A contusion results from a direct blow to the eye, while a concussion arises from the conduction of energy from a remote site to the target tissue. In both cases, massive disruption of the eye and its adnexa may result, including rupture of the globe.

A blow from a missile with a rough surface or sharp edges may also result in lacerations and abrasions. Cuts to the globe and eyelids should be checked to ensure that they are not full-thickness lacerations.

Foreign bodies in the eye remain the most common cause of disabling ocular injuries. These may be superficial, imbedded or intraocular, depending on the size, shape and speed of the body. Ferrous foreign bodies should be removed as quickly as possible to prevent siderosis.

Ocular siderosis is the formation of rust in the ocular tissues as a result of oxidation of iron contained in a foreign body. Its most frequent manifestation is a rust ring surrounding a superficial ferrous foreign body in the corneal epithelium. If the foreign body is lodged inside the eyeball, siderosis may lead to heterochromia, papillary mydriasis, iron deposition on the corneal endothelium and beneath the anterior lens capsule, cataract and changes in the retinal pigment epithelium (RPE). The patient can experience visual loss which may be profound and permanent without treatment.

THE WORKPLACE SURVEY (cont.)

OCULO-VISUAL HAZARD ANALYSIS (cont.)	**Mechanical Hazards (cont.)** Particles under 0.5 mm in diameter are usually too small to cause penetrating ocular injuries. However, these bodies may become imbedded in the ocular surface if propelled at high speed (e.g. sandblasting). Often present in airborne dusts and fumes, the tiny particles cause a foreign body sensation upon contact with the eye. Some foreign bodies may dissolve in the ocular fluids and cause chemical injuries in addition to the mechanical trauma. **Chemical Hazards** Workers may be exposed to vapours and fumes from volatile solvents and corrosive materials. While the tear film may protect the eye temporarily from the adverse effects of exposure to fumes of non-polar organic solvents, it provides no protection against polar solvents. The fumes of corrosive solutions such as strong acids and alkaline materials can cause severe irritation to the cornea and conjunctiva. Splash injuries are common among workers handling chemical solutions, comprising between 5 and 10% of all lost time eye injuries. Highly concentrated solutions cause severe sight-threatening chemical burns to the eye and adnexa. Immediate copious irrigation with cool water is necessary to limit the damage due to chemical splash. It should be noted that in weak solution, alkaline solutions penetrate the eye rapidly by saponification of cell membranes and cause much more severe injuries than acids of the same concentration, which are neutralised in the body fluids. **Electrical Hazards** When non-lethal, electrocution may result in damage to the central nervous system. In rare cases, an electric cataract can be observed. Electrical utility repair workers are often exposed to bright electric arcs from damaged power transmission lines, transformers, and isolation switches. Because of the high voltage and current levels involved, the arcs dissipate a large amount of energy as plasma (ionised air along the path of the arc), optical radiation (primarily visible light), and sound. Workers who come in contact with the arc and/or plasma may suffer third degree burns and electrocution. Full body protection is needed. Workers who are remote from the electric arc discharge may still be at risk of ocular injury. Showers of molten metal droplets may be generated at the contact points of the arc, and are a greater ocular hazard than the arc itself. **Optical Radiation Hazards** Optical radiation ranges from approximately 200 nm to 1 mm in the electromagnetic spectrum. For convenient reference, it is divided into the following wavebands: • UVC 200 to 280 nm • UVB 280 to 315 nm • UVA 315 to 380 nm • Visible light 380 to 780 nm • IR-A 780 to 1400 nm • IR-B 1400 to 3000 nm • IR-C 3000 nm to 1 mm Although most optical radiation injuries to the eye are associated with high level acute exposures (a large amount of radiant energy delivered in a relatively short time), long-term exposure to moderate levels of UVB, UVA and short wavelength visible light may result in chronic damage to the ocular tissues. Spectral transmittance of the ocular tissues and media will determine how deeply into the eye a given wavelength of optical radiation will penetrate. Ultraviolet (UV) and long-wavelength infrared (IR-B and IR-C) radiation affect structures in the anterior eye, while visible light and IR-A affect the retina and RPE.

THE WORKPLACE SURVEY (cont.)

Oculo-Visual Hazard Analysis (cont.)	**Optical Radiation Hazards (cont.)** For a discussion of optical radiation hazards, see *Ocular Effects of Radiant Energy* in "Environmental Vision: Interactions of the Eye, Vision, and the Environment" (Pitts and Kleinstein, 1993). Welder's flash and exposure to electric arcs (without electrocution) together account for about 10% of eye injuries. A comprehensive discussion of tinted lenses for protection against optical radiation hazards can be found in *Prescription of Absorptive Lenses* in "Borish's Clinical Refraction, 2nd Ed." (Benjamin), 2006. Table 2 (at the end of this chapter) lists commonly prescribed medications that are known to be photosensitising. Modern technology has developed many artificial light sources that may emit not only visible light but also significant amounts of UV and/or IR radiation. Examples include electric welding arcs, high pressure gas discharge lamps (e.g. xenon and mercury-xenon lamps), black light fluorescent lamps, projector lamps, tungsten halogen lamps, deuterium lamps and light emitting diodes. Lasers are available with a wide range of output wavelengths, beam power and temporal and spatial characteristics, and are found in many industrial, health care and recreational settings. The optometrist will be challenged to identify the optical radiation hazards and eye protective measures associated with these various light sources. Sunlight is a very important factor in the individual's total exposure to UVB radiation. The solar UVB level varies diurnally as well as seasonally, becoming significant when the sun is at an altitude of 30° above the horizon. Thus, solar exposures of 20 minutes duration between 10h00 and 16h00 in the summer may result in acute effects such as sunburn and mild photokeratitis, while a similar exposure at the same time of day in winter would not. It should be noted, however, that environmental UV exposure is also determined by the amount of UV scattered across the sky, and by ground reflectance. Surfaces such as fresh snow, white concrete, and white sand have UVB reflectances of over 90%; the effective UVB exposure is therefore almost double the direct solar irradiance in these environments. It is not surprising, then, that skiers suffer sunburn on their faces after a day on the slopes. UV reflectance from water is also quite high, thus anyone who works or engages in leisure activities on fresh or salt water requires UV protection for their eyes. Specular reflections from water are a significant source of disability and discomfort glare, and can be well controlled with polarising sunglass lenses. Individuals whose occupational and leisure time activities require them to be outdoors in the middle of the day are at higher risk of developing skin and eye damage due to the chronic high exposure to solar UVB. This is because the cellular damage is cumulative. There is particular concern about solar UVB exposure in childhood, when the eyes are transparent to UVB. It has been estimated that most individuals in Europe and North America accumulate over 50% of their lifetime exposure to solar UVB before the age of 18 years. It is thought that chronic high level UVB retinal exposure in childhood may be a contributing factor in the development of dry macular degeneration later in life. Individuals who have low levels of skin and eye pigmentation, and those taking photosensitising medications are also at higher risk. An additional recent concern has been the depletion of the ozone layer in the earth's stratosphere due to the action of atmospheric pollutants. Although only a very small amount is present (at sea level, the ozone in the stratosphere would be reduced to a layer just 3 cm thick), stratospheric ozone absorbs the UVC and most of the UVB in sunlight, shielding organisms at the earth's surface from this radiation. A reduction by 1% of the stratospheric ozone concentration results in a 1.1 to 1.4% increase in UVB irradiance at the earth's surface.

THE WORKPLACE SURVEY (cont.)

OCULO-VISUAL HAZARD ANALYSIS (cont.)	Ozone molecules are destroyed in a photochemical process catalysed by chlorine carried into the upper atmosphere by CFCs released from fire retardation, refrigeration and airconditioning systems. CFCs released at the surface of the earth take between 50 and 100 years to diffuse into the upper atmosphere; even if all CFC releases were stopped immediately, the problem of ozone depletion due to CFCs and the associated increase in solar UVB exposure would not end for another century. This presents a serious public health problem. The combination of increased life expectancy and high prevalence of sun exposure in occupational and leisure time activities has already resulted in markedly increased incidence of cataract and macular degeneration in the populations of North America and Europe. As environmental UVB irradiance levels increase over the next century, it is possible that the prevalence rates of these conditions will increase even more dramatically as the incidence among younger individuals increases. An additional problem is the increase in skin cancers associated with chronic high level sun exposure. The costs of these health consequences to the health care systems in the developed countries will be enormous. One way to prevent this scenario is to change people's attitude towards sun exposure. "Sun Awareness" programmes in Australia, Canada and the United States have led to greater public knowledge about the dangers of sun exposure to the skin and eyes. The Australian programmes have been extremely successful, resulting in a recent decrease in the incidence of skin cancers due to sun exposure. In addition, the meteorological services of Australia, Canada, the United Kingdom, the European Union and the United States have included information on solar UVB levels in their daily weather forecasts. The UV Index is a number between 0 and 15 which forecasts the intensity of UVB radiation in sunlight. A higher number implies greater risk of skin damage due to sunburn. On days when the UV Index is expected to be high, it is recommended that people avoid sun exposure during the hours of peak UV irradiance, and if this is not possible, they should use skin and eye protection (e.g. sunblock on the skin and UV-blocking sunglasses). Concerns about environmental exposure to UV radiation in sunlight has also led to the adoption of more strict standards for sunglasses. Manufacturers of sunglasses are taking steps to ensure that their products meet the requirements of the following standards: • ANSI Z80.3-2010 Requirements for non-prescription sunglasses and fashion eyewear (USA) • AS/NZ 1067-2003 Sunglasses and fashion spectacles (Australia) • BS 2724-1987 Sun glare eye protectors for general use (UK) • EN 172:1995 Specifications for sunglare filters used in personal eye-protectors for industrial use (CEN). **Ionising Radiation** Gamma rays, X-rays and UVC radiation interact with matter by ionising atoms and molecules. Particles arising from atomic and nuclear reactions such as alpha and beta particles, protons, neutrons and positrons interact with orbiting electrons directly to cause ionisation of atoms and molecules. They are often referred to collectively as “ionising radiation”. Ocular exposure may result in cataract, radiation retinopathy, and photokeratoconjunctivitis.

THE WORKPLACE SURVEY (cont.)

OCULO-VISUAL HAZARD ANALYSIS (cont.)	**Biological Materials** Workers handling biological materials must follow strict protocols to prevent contact with infectious agents, toxins and allergenic substances. The design of isolation garments used by some workers may limit their visual field. **Limits on Worker Exposure to Chemical and Physical Agents** The health effects of certain chemical and physical agents do not become apparent until a threshold exposure is reached. At this point, clinical signs and symptoms first become noticeable. Occupational exposure to ionising radiation, chemical agents and some physical agents (e.g. heat, humidity, optical radiation) is controlled by setting limits (maximum permissible exposure or MPE) at a fraction of the threshold limiting values (TLV) which result in clinical onset of adverse effects. The MPE may be expressed as a concentration in air (organic solvents, dusts), dose rate (ionising radiation, optical radiation), or total dose (ionising radiation). A MPE expressed as total dose is specified for a time period (e.g. 8 hours, 1 week, 1 month, 1 year, etc). A total dose MPE may also vary according to the dose rate. **Health Surveillance Programmes** An occupational oculo-visual assessment may be appropriate when long-term repeated exposure to hazardous materials may lead to changes in ocular health or visual function. Vision standards must be established for each job area and task (see below). The procedures comprising the assessment should detect workers who do not meet the vision standard with high sensitivity and specificity. Ownership and accessibility of the workers' health records are a matter of great concern to both employees and their employers. The confidentiality of the patient-practitioner relationship is often considered compromised unless appropriate safeguards are established (see below). **Guidelines and Standards** The TLV and MPE values for most chemical substances and physical hazards (e.g. optical radiation, heat, cold) are contained in ISO, DIN, EC, ANSI and/or NIOSH publications. Good sources include the American Conference of Governmental Industrial Hygienists (ACGIH) publication "Threshold Limit Values" which is revised each year, and the Current Intelligence Bulletins series published by NIOSH. Information may also be available from the local occupational health and safety authority, as well as the industrial hygienist or occupational safety officer at the workplace. Hazardous Material Data Sheets which contain information on safe handling and storage procedures as well as exposure limits, should be available for review at the workplace.
ERGONOMIC FACTORS	**Workstation Layout and Visual Demands Analysis** General considerations include: • **Working distances and lines of sight** Consider whether there are any special working distances at the workstation, as well as a need for the head or eyes to turn significant amounts from primary gaze position to take up fixation. Also, consider whether the worker is sitting, standing, or looking at overhead targets. Worker posture may be related to complaints of oculo-visual discomfort, particularly if the worker must maintain awkward head and eye positions or corrective lenses are not appropriate for the fixation distances.

THE WORKPLACE SURVEY (cont.)

ERGONOMIC FACTORS (cont.)

- **General illumination**
  Consider the level of illumination, type of luminaire, existence of glare sources in the worker's field of view. Is there a problem with flickering light sources? Are there large windows which provide daylight that would be a significant glare source? Is there low general illumination with task lighting? Are there areas which are inadequately illuminated for the tasks being carried out?

  The Illumination Engineering Society (IES) publishes the Lighting Handbook (IES, 2011) which is the authoritative reference on the theory and practice of measuring and designing lighting. The IES also recommends illuminance levels for a variety of visual tasks. Illumination for these tasks can be accomplished by general illumination, task lighting and/or supplementary lighting. Visual tasks with high demand for contrast and/or resolution generally require higher levels of illumination.

  Recommended illuminance levels for visual tasks are usually specified as ranges of illumination. Individual adjustments are needed for visual comfort and control of glare.

• Public spaces (reception area, corridors)	General lighting	20-50 lux
• Occasional visual tasks	General lighting	100-200 lux
• Tasks with medium contrast or small size	Task lighting	500-1000 lux
• Tasks with low contrast or small size	Task lighting	1000-2000 lux
• Prolonged or exacting visual tasks	Supplementary	5000-10000 lux

  The factors to be considered in lighting design are summarised by Gupta and Koshel (2010). Room dimensions may affect luminaire positioning and size, and the type of light source used.

  Glare is light that interferes with vision or adversely affects visual performance. It may affect the luminance contrast between the object of regard and the background. Veiling or disability glare is light that interferes with visual performance or visibility. An example would be the light scattered through the air and the ocular media from a flashlight that obscures the visibility of an object viewed next to the light source. Discomfort glare is light of sufficient intensity that it causes discomfort for the observer and may also interfere with the observer's vision. Taking the previous example of a flashlight, if it is so bright that the observer experiences discomfort while looking at the scene, then there is discomfort glare in addition to the veiling glare.

  It should be noted that the luminous intensity of a light source is not an indication of whether it is the cause of glare. The position of the source relative to the object of regard, the luminance of the object of regard compared to the light source, and the state of light adaptation of the eye all play a role in determining whether disability and/or discomfort glare are present.

- **Inappropriate Illumination**
  Illumination of the workplace may be too high for comfortable vision, or too low for optimal resolution, contrast sensitivity and colour perception. For example, an office with dim general illumination and intense task lighting may provide satisfactory illumination at the desks, but be insufficient for maintenance staff to see areas of the floor which need cleaning or repair. Office spaces with large windows facing the mid-day sun often have problems with sunlight and heat buildup, especially when computer equipment and VDTs are installed.

THE WORKPLACE SURVEY (cont.)

ERGONOMIC FACTORS (cont.)

- **Inappropriate Illumination (cont.)**
  In some instances, the quality of the lighting is inappropriate. An example would be the use of low pressure sodium lamps in a storage area where stock is identified by colour-coded labels. The absence of short wavelength (blue and green) light in the lamp emission would render blue and green labels as either black or shades of grey even to most individuals with normal colour vision. Colour identification and discrimination would be severely impaired, negating the efficacy of the colour code. For individuals with colour vision defects, the effect may be even more severe.

  The spectral power distribution of a light source with its effect on colour perception is one aspect of the quality of lighting. Other aspects that should be considered include the potential for causing disability and discomfort glare, and the potential for flicker to adversely affect vision. These factors may affect the aesthetics of vision in a given setting – does the visual environment encourage relaxation (e.g. dimmer general illumination in a restaurant) or excite the observer (the bright flashing lights of a casino or amusement park).

- **Characteristics of reading material or visual targets**
  Consider size, colour, contrast and luminance of the objects being viewed by the worker. Does the general illumination at the workstation decrease target contrast, make colour discrimination more difficult, or otherwise adversely affect visibility of the objects? Is the worker required to view moving objects and, if so, in what direction, and how fast do they move? Does the worker have any complaints about visual discomfort or fatigue?

Computer Monitors – Computer Vision Syndrome
Most worker complaints concerning computer monitors, often referred to in the literature as video display terminals (VDTs), relate to the ergonomic design of the workstation, glare interfering with visibility of the VDT screen, or visual discomfort due to inadequate refractive correction or uncorrected oculomotor imbalance.

Consider the following:

- **Visual demands**
  What is the nature of the visual task? Is it word processing, data entry, CAD-CAM work? Is it graphics or text intensive? What are the needs to read / view hard copy?

  Consider the size of the VDT screen and the pixel size as it relates to resolution and image quality. Additional factors: non-interlaced VGA or sVGA to reduce effect of flicker; character size, colour and contrast on the screen; room illumination and sources of discomfort and veiling glare in the immediate surround of the VDT.

- **Workstation design**
  Is the workstation fully adjustable for a VDT operator, or is the computer system set up on conventional office furniture? Consider stature and posture of worker when working at the VDT, also gaze position to see VDT and source documents, working distances to screen, keyboard, hard copy. The centre of the VDT screen should be approximately 20 cm below the primary gaze position (straight ahead distance viewing) of the worker. Check keyboard and desk height, foot support and lower back support. Does task lighting or general room lighting act as a glare source? Does lighting for an adjacent workstation act as a glare source? Fatigue and discomfort is more often due to poor workstation physical design than due to problems with worker's vision.

THE WORKPLACE SURVEY (cont.)

ERGONOMIC FACTORS (cont.)	
	• **Worker's vision** Visual complaints may relate to uncorrected or inadequately corrected ametropia, deficiencies of binocularity, accommodative fatigue. In presbyopic workers, the reading addition is usually too high and the segment position of a bifocal lens inappropriate for VDT use at 60 cm working distance. Intense concentration required of work at the VDT will reduce the rate of blinking. Individuals with dry eyes and contact lens wearers may complain of ocular irritation due to decreased blinking. • **Solving the problem of VDT-related complaints** The first step in dealing with VDT-related complaints is to ensure that the workstation has been properly adjusted to the worker. The keyboard and monitor should be adjusted to proper height and distance directly in front of the worker's seat. The chair height should be adjusted for optimal back and foot support, ensuring that proper posture is maintained. A copy holder should be mounted beside the monitor screen at the same working distance for intensive word processing or data entry. It may be necessary to move or alter the workstation setup to eliminate sources of veiling or reflected glare from the worker's field of view; light shields or antiglare screens may be helpful. It is only after these changes have been made to the physical layout that the visual demands can be dealt with. Some complaints may be due to an improperly adjusted monitor. Adjusting screen working distance and character colour, brightness and contrast may be all that is needed. A monitor with poor resolution or coarse dot pitch may require replacement with a better quality unit. The worker's spectacle correction should be appropriate for the working distance, taking into account both binocular function and accommodative demand. This is especially important when the worker's habitual correction does not provide a full correction of the ametropia. Presbyopic workers may require special occupational lenses to optimise their vision at the VDT, especially if the reading addition is +1.75 or greater. Examples of these lens designs are the SmartSeg (Sola), Zeiss Business, Essilor Interview and modified progressive addition (multifocal) lenses such as Gradal RD (Zeiss), Tact (Hoya) and Varilux Computer (Essilor). Recently, a number of lens manufacturers have introduced lenses intended to relieve accommodative stress in pre-presbyopic patients. Examples are the Essilor Anti-Fatigue and the Nikon Relaxsee. The so-called VDT tints and coatings are normally of little or no use in eliminating the worker's visual complaints with VDT use. When the worker complains of burning, itching or uncomfortable eyes, the tear film should be evaluated. Blinking exercises may be helpful to contact lens wearers and workers with dry eyes. Tear substitutes or ocular lubricants may also help. If the workplace is very dry, space humidifiers may be necessary. Symptoms of ocular fatigue may be alleviated with properly fitted occupational corrective lenses. A break of 5 to 10 minutes from intense near point work at the VDT or desktop every 1 to 2 hours may also help to relieve ocular fatigue. This break is simply a task at a different working distance intended to change the level of accommodative demand.

THE WORKPLACE SURVEY (cont.)

WORKPLACE LIGHTING ASSESSMENT	See below

Principles of Radiometry and Photometry

Radiometry is the science of detection and measurement of electromagnetic energy at optical wavelengths. For the practising optometrist, the optical wavelengths of concern range from about 190 nm in the high-energy ultraviolet region of the spectrum through visible light (380 to 780 nm) into the far infrared (1 mm). The physical mechanisms by which optical radiation interacts with matter explain how radiant energy affects the eye and visual system and how we measure it.

Photometry is the science of measurement of visible light, defined as electromagnetic energy that is detectable by the human eye. All quantities are weighted by the spectral response of the eye which is also referred to as the CIE Standard Observer or the spectral luminous efficiency function for photopic vision. Its measurements are limited to the waveband 380 to 780 nm.

While radiometry measures the quantity of electromagnetic energy present, photometry measures the ability of light to produce a defined simulation of human vision.

We consider the radiant energy as it is emitted by an optical source and travels through an isotropic optical medium. An isotropic medium is one in which the optical properties are the same, regardless of the direction light travels. For example, the index of refraction and the spectral transmittance of an isotropic optical medium are constant. The laws of geometrical and physical optics predict how the radiation propagates and forms an image (if any). At any location within the optical medium, we can describe the amount of radiant energy arriving and leaving in terms of time and spatial distribution. This is the concept of energy flow or flux (Figure 1).

The radiant energy Qe is measured in Joules (J) in the SI system. Energy per unit of time or flux is radiant power or flux ϕ which is measured in watts (W) or J/s. For continuous sources, the most convenient measurement is ϕ. Qe is usually measured for a source that is flashing or emits a single pulse of energy.

The way radiant energy leaves a source or falls upon a receiving surface can be described in several ways. The direction of propagation of the radiant energy can also be taken into account.

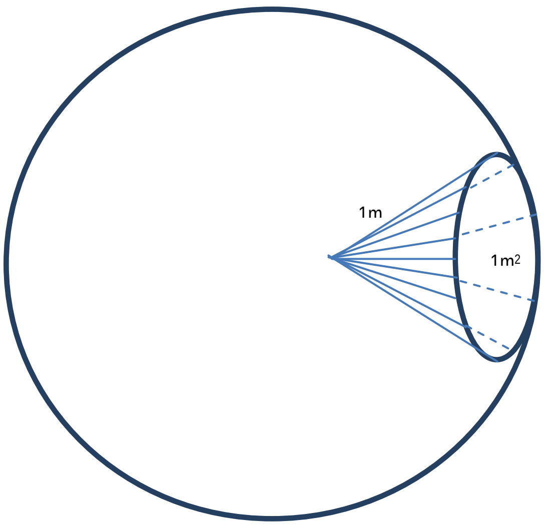

Figure 1: *The amount of radiant energy arriving and leaving can be described in terms of spatial distribution*

THE WORKPLACE SURVEY (cont.)

WORKPLACE LIGHTING ASSESSMENT (cont.)	Consider a sphere of radius 1 m on whose surface is traced out a circular area of 1 m^2. From the centre of the sphere, this area represents a solid angle of 1 steradian (sr). The sphere's surface has a total solid angle of 4π sr. The solid angle can be used to describe the propagation of radiant energy in a given direction. The radiant intensity I_e of a source is the radiant power per unit solid angle (W/sr) travelling in a given direction. Another useful measurement to describe the source output is the intensity per unit area, or radiance L_e (W/m^2-sr). On a receiving surface, the radiant power per unit area is the irradiance Ee and the total energy received per unit area is the radiant exposure He. Although it is often assumed that the radiant energy departs from a source or arrives at a receiver along the normal to the surface, this is not necessarily the only consideration. Radiance, irradiance and exposure can also be determined at a direction θ from the normal to the surface. In this case, the projected area of the surface in that direction must be used in the calculation. The projected area is given by A cosθ, where A is the area of the surface. This leads to the concept of cosine correction of measurements. Meters designed to measure irradiance and exposure levels independent of the direction of propagation of the radiant flux are described as "cosine corrected." **Relationship Between Radiometric and Photometric Units** Since photometry is related to the human visual response to light, its fundamental unit of measurement, the candela, must take into account the spectral sensitivity of the eye as well as the spectral content of the light. There are different spectral sensitivity functions for photopic and scotopic vision defined for the CIE standard observer, which are designated as V (λ) and V' (λ) respectively. The candela (cd) is defined as the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian. This is the only SI unit of measurement that is linked to human physiology. The luminous flux φv is defined as: $\Phi_v = K_m \int \Phi_\lambda V(\lambda) d\lambda$ Where φ_λ is the spectral radiant flux and K_m is the constant 683 lm/W. Its unit is the lumen or cd-sr. The function V(λ) is the spectral sensitivity function of the eye, and may be either the photopic or scotopic function, as is appropriate for the circumstances. Tabulated values of V(λ) are usually at 2, 5 or 10 nm intervals; the interval width is substituted for dλ in the equation. It is then possible to describe the luminance of a source and illuminance and luminous exposure at a receiving surface in ways similar to source radiance and irradiance and radiant exposure at a receiving surface. The SI unit for illuminance is the *lux* or lm/m^2. Since photometric quantities are related to the visual perception of light, it should be noted that they only include optical radiation between 380 and 760 nm. While radiant energy in the UV and IR may be present, these wavebands do not contribute to the photometric properties.

THE WORKPLACE SURVEY (cont.)

Workplace Lighting Assessment (cont.)	**Radiometers and Photometers** There are a wide variety of instruments to measure light. They have in common components to collect light and convert the radiant energy into an electronic signal, an electronic circuit that converts the electronic signal into a measurement, and a way to display the result. Those instruments that directly measure the amount of radiant energy present are referred to as *radiometers.* If the instrument is capable of measuring the spectral distribution of radiant energy across the spectrum, it is called a *spectroradiometer*. Most radiometers measure either irradiance or total radiant energy. Irradiance measurements are more appropriate for continuous sources, while energy meters are more suitable for measuring pulsed sources. The spectral bandwidth, wavelength resolution, sensitivity and responsivity of an instrument are important performance characteristics that must be matched to the properties of the light source being measured. An instrument that is calibrated to produce a reading of luminous intensity or illuminance, i.e. how the light appears to the human eye, is a *photometer*. Operating characteristics similar to those of radiometers can be specified. Spectroradiometric data can be used to calculate photometric properties of a light source. Instruments equipped with imbedded microprocessors or computer control interfaces can provide both radiometric and photometric data. However, it is not possible to fully characterise the radiometric characteristics of a light source by the reverse calculation based on photometric measurements, since these are limited to the visual spectrum. **Lighting Assessment Procedure** A basic lighting assessment will include an inventory of the type, dimensions and distribution of the luminaires in the room or space being examined. This will include light fixtures for general, task and supplementary lighting. A floor plan with this information should be prepared. The type of lamp or light source in each of the luminaires is recorded. Irradiance and illuminance measurements are made at all important work surfaces with customary illumination. Notes should be taken of any comments about the effect of the lighting on the ability to perform the work conducted at each work surface. At each work surface, the position and intensity of potential or actual sources of disability and/or discomfort glare should be noted. These data can be compared with the overall illumination of the work surface as well as the recommended illuminance levels for the visual tasks being performed. Lighting assessment protocols are set out in the IES *Lighting Handbook* for many environments, both interior and exterior.

MATCHING THE WORKER TO THE TASK

VISUAL STANDARDS	The level of visual performance for each job area and activity should be that needed to work safely and efficiently. A visual task analysis should be conducted to determine the visual demands of the work activity. For example, the size of the smallest visual details that must be seen to perform the task, and the working distance between the object of regard and the worker's eyes can be measured. Is the work done at one viewing distance, or is the worker expected to change fixation to different positions and distances in front of the eyes? Is depth perception or stereo vision needed to perform the task? Does the work require colour identification and discrimination? Would abnormal colour vision adversely affect the ability of the worker to perform the task? What is the typical illumination level, and is there disability or discomfort glare as a result? Accordingly, one can specify the minimum acceptable level of visual acuity, binocular function, colour vision and stereopsis. If there are possible adverse effects due to occupational exposure to chemicals, radiant energy or other physical hazards, minimum criteria for ocular health status may also be needed. A programme of periodic ocular health assessments may be appropriate. With the exception of workers in the transportation industry and military and police personnel, whose visual performance may be set by regulations or government policy, there are usually no documented occupational visual standards. The critical issue must be safety of the worker and other employees as well as the public. It is therefore important that visual standards not be set arbitrarily, but rather on the basis of the workplace survey, with due regard to the visual task analysis. Many jurisdictions have regulations setting out visual requirements for drivers. These include monocular visual acuity at distance, distance phoria and stereopsis, colour vision, and visual fields, all of which can be tested by a layperson using a vision screening tester.
THE OCCUPATIONAL OCULO-VISUAL ASSESSMENT	It is rare that an occupational oculo-visual assessment will be as comprehensive or intensive a procedure as a general oculo-visual assessment. Tests are selected on the basis of the established visual standards for the job and the adverse effects of any known hazards associated with it. Vision screening instruments may be employed to obtain basic information on a worker's vision. These instruments can be operated by a lay person and offer a selection of tests which measure distance and near visual acuities, colour vision, depth perception and horizontal and vertical phorias. Some models may include other tests of binocular vision and glare recovery. There is no ocular health assessment. The Modified Clinical Technique (MCT) is sometimes used as an occupational vision screening procedure. The battery of tests includes a case history (with emphasis on past exposure to the workplace hazards of the job in question, ocular and general health history, and history of vision care and previous injuries, if any), habitual visual acuity at distance and near, objective binocular function assessment, stereopsis, amplitude of accommodation, colour vision, retinoscopy, external health and pupil assessment, and direct ophthalmoscopy. When a worker does not meet the visual standards for the job, a referral for a full oculo-visual assessment is made. The occupational vision assessment may be performed as a pre-employment procedure to determine the suitability of the worker to perform a specific task. Failure to meet the criteria would result in assignment to a different task if the deficiency cannot be corrected. As a pre-employment assessment, the purpose is to screen out workers whose vision would make their job performance hazardous to both themselves and fellow workers.

MATCHING THE WORKER TO THE TASK (cont.)

THE OCCUPATIONAL OCULO-VISUAL ASSESSMENT (cont.)	Workers may be subject to periodic re-assessment. This is a monitoring programme intended to identify workers who are developing early signs or symptoms of occupational eye disease or dysfunction. A worker who is identified by this assessment would be referred for rehabilitation or transferred to another job function until the signs and symptoms disappear. The nature of the occupational hazards of the workplace may make it prudent for workers to undergo a post-employment assessment. This is intended to reduce an employer's liability for occupationally induced oculo-visual disease or dysfunction by showing that upon leaving employment the worker was free of signs and symptoms. The worker may also be assured that on leaving employment there is no detectable change in ocular health status. It should be realised by both the employee and employer that exposure to some occupational hazards may not have short-term adverse effects; serious deleterious effects may appear long after the employee has left service. Regardless of how the occupational oculo-visual assessment is to be carried out, the optometrist must take care that the patient-practitioner confidentiality of information is protected as much as possible when reporting to the employer and/or government agencies on adverse changes in the oculo-visual status of the worker. The interests of both the worker (good health and job security) and the employer (a workplace free of accident or injury) must be satisfied.
PERSONAL PROTECTIVE STRATEGIES	There are three general approaches to occupational protection: avoidance, shielding, and minimal exposure. **Avoidance** In principle, this is the ideal approach to occupational protection. Physical barriers isolate the hazardous situation from the worker. A good example of this type of approach is the remote manipulation of radioactive materials in the nuclear industry. **Shielding** If the hazard cannot be completely isolated, a worker may be provided with personal protective equipment that physically shields him or her from the hazard. Protective clothing and eye protective devices fall into this category. **Minimal exposure** Some workers cannot be isolated or adequately shielded from physical hazards. Although these workers should be provided with personal protective equipment, an additional safety measure is implemented. This is to place a limit on the worker's exposure to the hazard which is well below the TLV. The exposure limit is the Maximum Permissible Exposure (MPE). This minimises the worker's contact with the hazard and is expressed as a maximum permitted dose rate or total dose. This approach is often taken with regard to exposure to chemicals or ionising radiation. **Personal Protective Equipment** Selection of personal protective equipment such as eye and face protectors must balance effective worker protection and cost. The workplace hazard analysis and consultation with workplace safety personnel will enable the optometrist to specify which type of eye and face protection is appropriate, and whether workers who use spectacles or contact lenses need a different or modified protector design. Note however, that the workplace safety officer has the responsibility of approving the selection of safety eyewear, and should be consulted in this matter.

MATCHING THE WORKER TO THE TASK (cont.)

PERSONAL PROTECTIVE STRATEGIES (cont.)	**Personal Protective Equipment (cont.)** Since industrial eye and face protectors are rated by the manufacturers according to the hazard classifications of the various protective standards (e.g. EN, ISO, British CSA and ANSI standards), the optometrist should be able to make appropriate selections based upon the workplace hazard analysis. Safety spectacles are probably the most widely used occupational eye protectors. Designed to protect the contents of the orbit from the front and side, these appliances usually feature full eyewires, side shields and polycarbonate lenses with a minimum thickness of 2 mm (3 mm when there is high risk of high energy impact hazards). Goggles may be used with or without safety spectacles for enhanced protection from a wide variety of hazards. Face shields and various welding helmets should be worn in combination with safety spectacles. Where appropriate, filter lenses that protect against the optical radiation hazards of welding operations should be used. The cost of occupational corrective lenses and eye protectors can be significant in certain instances, e.g. VDT lenses. While large employers may be required by regulation to supply occupational lenses and protectors without cost to their employees, this may not be the case with smaller businesses and self-employed individuals. In such cases, the optometrist must carefully balance the costs against the benefits of the protective appliance being chosen. One aspect of occupational vision plans that is sometimes ignored is the need to educate the workers on the need to use eye protection at all times while on the job. The workers must be discouraged from adopting the "Other Guy" or "Not Me" attitude that eye protection is for everyone else. The use of eye protectors should be mandatory for all employees entering certain areas of the workplace, and must be strictly enforced. Compliance with a safety eyewear policy can be encouraged by ensuring that wherever possible, the eyewear is cosmetically appealing, comfortable to wear and provides good vision. Appliances that can be readily adjusted to fit (and do not lose adjustment) should be chosen. When prescription lenses are fitted to the appliance, the optometrist should ensure that lens and frame parameters are verified prior to dispensing to the worker. Proper lens cleaning facilities should be set up throughout the workplace to encourage workers to maintain their eyewear and inspect it regularly for defects.

PITFALLS OF INDUSTRIAL CONSULTING

THE KISS PRINCIPLE	KISS = "Keep it simple, stupid!" The optometrist who engages in industrial vision consulting must work with employees, supervisors, management and safety personnel. Communications must be kept free of technical jargon. Policies and procedures should be set out in as simple language as possible to avoid misunderstandings over the purpose and processes involved in the industrial vision programme. The practitioner must also know his or her limitations in providing the diagnostic, dispensing and consulting services. Set realistic goals and timelines. An overambitious programme that cannot be delivered as promised damages the practitioner's credibility with all parties involved.
FEES - CHASING THE CLIENT AWAY	An industrial vision programme is a contract negotiated with the employer for diagnostic, dispensing and consulting services. It is important to realise that the balance of costs and benefits will dictate whether the terms are acceptable to the employer who must pay for them. The employer must be convinced that the proposed programme is beneficial and cost effective. While the optometrist must never undervalue his or her professional time and expertise, setting a high fee may discourage the employer from following through with the programme.
WORKER VS EMPLOYER CONFLICTS	Because the optometrist is usually brought into the workplace by the employer or management to deliver an occupational vision programme, employees may consider the optometrist to be an agent of management. To be effective, the practitioner must ensure that the employees understand that the programme is being set up in their best interest and co-operate. Thus, employee representatives should be involved in the process of establishing the programme and any reporting protocol arising from it. It should be made clear to both employees and management that the information obtained from the occupational oculo-visual assessment is only intended to ensure that the worker's oculo-visual status meets the standards established for a particular task. There should also be a clear statement of what happens if a worker does not meet the oculo-visual criteria. Information on an employee who has failed the criteria must be passed to the workplace safety officer so that an appropriate referral can be made. The information will not be used for any other purpose. The contract for the occupational vision plan should include safeguards for confidentiality of information gathered by the optometrist. In some jurisdictions, privacy legislation that protects the confidentiality of the worker's health information may take precedence over such contract clauses. Confidentiality of worker information is a highly sensitive issue, but it is not the only potential source of ethical conflicts. There is a potential conflict of interest in that the practitioner who monitors the oculo-visual status of the workforce is also responsible under the occupational vision plan for prescribing and/or supplying appropriate safety eyewear. The contract should clearly state the process for approval of purchases, a schedule of fees and the terms of payment.

VISUAL HEALTH IN SELECTED INDUSTRIES

The following points of consideration are not meant to be exhaustive or comprehensive. They are provided for guidance and as a starting point for discussion.

CHEMICAL INDUSTRY	**Ocular Hazard** • Systemic / ocular chronic exposure to chemicals • Chemical splash • Impact • Optical radiation **Specialised Visual Tasks** • Reading colour-coded labels • Detection and identification of colour indicators **Eye Protection** • Safety spectacles • Goggles - protection against splash, dust, gases, optical radiation, impact
OUTDOOR WORKER	**Ocular Hazard** • Solar UV exposure • Impact • Chemical exposure **Specialised Visual Tasks** • Reading coloured signs, signals **Eye Protection** • UV blocking lenses • Safety spectacles • Goggles and face shields as appropriate for task
WELDERS	**Ocular Hazard** • Optical radiation – UV, visible, IR • Impact • Dust, gases **Specialised Visual Tasks** • Lighting welding flame / arc • Locating site of weld **Eye Protection** • Safety spectacles • Welding goggles / helmets • Welding filters (may be mounted in helmet as window or as lenses in spectacles / goggles, depending on type of welding)
LASER WORKER	**Ocular Hazard** • Optical radiation • Non-linear radiation effects (fast pulse lasers) • Gases and fumes • Fire • Impact **Specialised Visual Tasks** • Varies with job **Eye Protection** • Goggles with protective filter matched to laser line – frontal and side protection

VISUAL HEALTH IN SELECTED INDUSTRIES (cont.)

TRANSPORTATION INDUSTRY	**Ocular Hazard** • Solar UV radiation • Optical radiation from lamps • Impact • Chemical? **Specialised Visual Tasks** • Coloured signal detection and identification • Peripheral motion detection • Vision under low illumination and/or low contrast conditions **Eye Protection** • Tinted lenses for optical radiation protection • Safety spectacles as appropriate
HEALTH CARE WORKER	**Ocular Hazard** • Impact • Splash • Chemical (drugs, disinfection and cleaning materials) • Optical radiation (medical lamps / lasers) • Xrays **Specialised Visual Tasks** • Reading coloured labels, indicator strips • Identification of coloured signal lights **Eye Protection** • Safety spectacles • Goggles (splash, optical radiation)

Table 2: Commonly Prescribed Photosensitising Drugs

Class of Drug	Category	Generic Name	Effect with UVR
Antibiotics	Sulfonamides	Sulfacetamide Sulfanilamide	Phototoxic Photoallergic
	Tetracyclines	Cholotetracycline Oxytetracycline Doxytetracycline	Phototoxic Cataracts
Hyperglycemics	Sulfonylureas	Chloropropamide Tolbutamide	Phototoxic
Diuretics	Chlorothiazides	Benzothiadiazide Quinethazone Trichloromethazide	Phototoxic
Antipsychotics	Phenothiazides	Chlorpromazine Promethazine Mepazine	Phototoxic Photoallergic
Antianxiety	Chlordiazepoxides	Librium Valium	Phototoxic
Photochemotherapy	Furocoumarins	8-Methoxypsoralen Trimethylpsoralen	Phototoxic
Hormones	Oral contraceptives	Estrogen Progesterone	Phototoxic

Adapted from: Pitts DG and Kleinstein RN. Environmental Vision: Interactions of the Eye, Vision and the Environment. London: Butterworth Heinemann, 1993.

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