Luminance In the Occupational Visual Field: An Evaluation of Office Workstations

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Abstract

Inappropriate lighting is one of the most common causes of visual disturbances in office workers. Visual demand can also lead to musculoskeletal problems such as tension neck syndrome. On the other hand, appropriate location of light sources and a suitable level of illumination can enhance visual capacity. A rational approach to visual risk assessment of tasks and workstations involves measurements in the occupational visual field, and in particular luminance measurement. We report a large scale photometric evaluation in six companies in northern and central Italy. Operator tasks were predominantly administrative with some computer aided design activity.

Occupational visual field luminance ratios were found to be excessively high (>1:250 cd/m^2) in 19% of workstations (n = 100), moderately high (1:100-1:250 cd/m^2) in 20% and considered satisfactory (<1:100 cd/m^2) in 61%. Illuminance in the working plane ranged from 100-2500 lux and correlated poorly with luminance. Parameters were highly dependent on light fitting position and window location.

The survey demonstrated shortcomings in lighting design and workstation layout, both from artificial and natural sources. It is recommended that photometric assessment incorporate both luminance (occupational visual field) and illuminance measurements.

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Introduction

Inappropriate lighting, both natural and artificial, is one of the most common causes of ocular and visual complaints in office workers. High contrasts between light and dark areas of the visual field, as well as stray light "washing out" screen images, can make visual processing difficult and lead to awkward postures.

Visual tasks have become more demanding in last 30 years due to the ubiquity of screen-based equipment. Although there is a greater awareness of office ergonomics, a review of the literature suggests that the prevalence and the profile of workers' visual complaints has not changed substantially (see Table 1).

TABLE 1.

Prevalence of visual complaints in VDU operators*

Authors	Year	Population studied	Frequency of complaints
Ghiringhelli	1980	Swiss VDT operators	76%
Läubli et al.	1980	German VDT operators	65%
Starr et al.	1982	VDT in telephone operators	76%
Dain et al.	1985	VDT operators	25%
WHO	1987	VDT operators	45%
Wibom and Carlsson	1987	Scandinavian VDT operators	70%
Piccoli et al.	1989	Italian VDT operators	>50%
Scullica and Rechichi	1989	Italian VDT operators	25%
Lindner	1994	VDT operators	58%
Thomson	1998	English CDT operators	50%
Fenga	2008	Italian VDT operators	74%
Megwas and Aguboshim	2009	Nigerian VDT operators	90%
Shrestha et al.	2011	Nepalese VDT operators	92%
Tebboune and Mebarki	2012	Algerian VDT operators	85%
Han	2013	VDT Chinese college students	95%

**The average in the period 1980-2013 is 65%, between 1980 and 1996 is 54% and between 1996 and 2013 is 81%.*

In this paper, we review the complex factors that determine visual load and influence complaints, with a focus on office lighting. We report a large scale photometric evaluation in six companies and 100 workstations where operator tasks were predominantly administrative, with some computer aided design activity.

Visual discomfort and its relationship with visual effort and lighting

An office Visual Display Unit (VDU) operator typically focusses on images and objects at short distances, commonly below one metre, activating intense accommodation of the eye.This is often for extended periods (many hours a day, sometimes without any break) and in environments which restrict the variation of near and far vision (due to the presence of partitions, walls, etc.) overloading ocular motility/binocularity functions.

As a consequence, there is a requirement for sustained accommodation and convergence effort. This is accompanied by a continuous pupillary adjustment. From a physiological standpoint, it activates a complex physiologic mechanism known as "sinkinesia" or "fixation triad", controlled by the Edinger-Westphal mesencephalon nuclei, the role of which is essential to allow the formation of sharp images, on both eyes (binocular vision). This is achieved by the simulateneous contribution of three kind of muscles (inside and outside the eye globe); the ciliary muscle, to place the image into focus; the extraocular muscles, to position the image on the retina, in particular, on the fovea (the central area of the retina of 5.5 mm in diameter, where there is maximum resolution), for optimal visual acuity (VA); and the iris sphincter muscle, to regulate the amount of light entering the eye.

In ideal conditions, the visual and neuromuscular system, controlling accommodation and convergence, allow for: high precision (optimal focus and fovealization of the image to discern small details); rapid response (for clear and comfortable vision, when observing screen, keyboard and any documents, with latency within a fraction of a second); and stamina (high efficiency for hours every day).

However, in many circumstances, these systems are overloaded. In addition, where there is near-continuous light stimulation of variable intensity and origin, pupillary reflexes (fast) and retinal adaptation (slow) mechanisms can be overloaded.

In practice, a VDU operator's activity is constrained by (i) the assigned tasks (which may be inflexible), (ii) structural characteristics of the work station (not fully adjustable) and (iii) screen and document placement (often squeezed in a limited space). During intense work the operator attention is predominantly concerned with the screen, keyboard, documents, devices, etc. Accordingly, the ocular fixation (gaze) covers a limited area, termed the Occupational Visual Field (OVF), defined as the part of space inside which the operator must primarily look at, to carry out the assigned work tasks.

A VDU operator typically keeps an average head-screen observation distance of approximately 80 cm. (Piccoli 2007). The OVF can be depicted as a cone with the vertex at the bridge of the nose (nasion), with an angular width which oscillates between +/-25 and+/-35 degrees in relation to the fixation axis, aimed at the centre of the screen. This is illustrated in Figure 1, where the average screen viewing distance in this case is 64 cm, assessed objectively with ultrasound (Piccoli 2001).

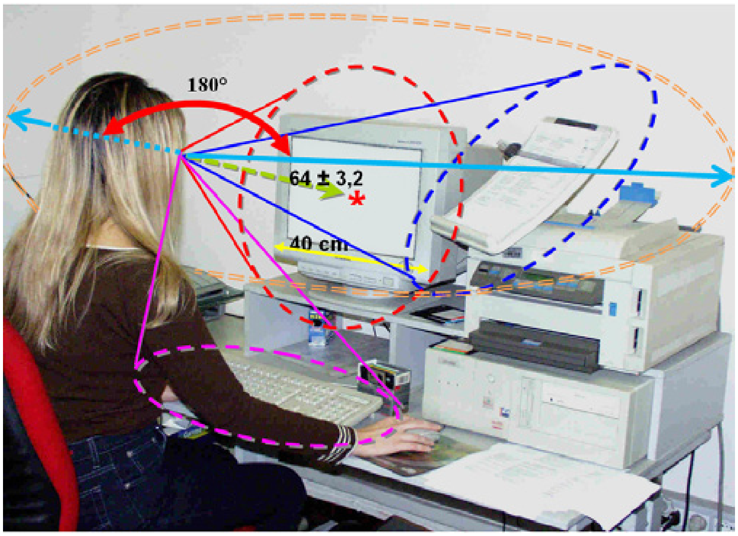

FIGURE 1

The Occupational Visual Field for a VDU Operator (observing screen, document holder and keyboard).

The effect of inappropriate lighting

Owing to relatively slow retinal adaptation, heterogeneous light distributions within the OVF produces a greater disturbing effect than distributions in the peripheral field of view.

Bright objects in the visual field, other than the objects of interest, potentially interfere with the physiologic visual and perceptive mechanisms, as well as the cognitive processes of the operator. In an attempt to overcome this interference, the worker may adopt a poor posture in an otherwise well-designed work station (Grieco and Molteni, 1999).

Therefore, it is possible to classify two groups of factors predominantly responsible for the typical ocular/visual discomfort and disorders of VDU operators; i) those caused by overloading of accommodation and convergence (related to near visual effort); ii) those caused by overloading of pupillary motility and retinal adaptation (related to the lighting conditions at the work station).

These can be exacerbated by a range of individual factors. Visual disturbances can be more prevalent among workers who need (or do not have) adequate optical correction, those suffering from ocular motility impairments and those affected by degenerative pathologies causing a marked reduction of visual acuity (maculopathy, cataract, pseudophakia, keratoconus, dry eye syndrome, etc.), pathologies commonly found in general and working population. (Resnikoff *et al.,* 2008).

Enviromental factors inluding chemicals (affecting indoor air quality) and microclimate (high air speed as well as low relative humidity), can act on the ocular surface (Wolkoff *et al.,* 2005) and further exacerbate problems.

In summary, ocular and visual disturbancies originate from different components of the visual system. Lighting is just one these, acting synergistically with other adverse factors. According to the International Commission on Occupational Health, Scientific Committee on Work and Vision (Piccoli *et al.,* 2003), these symptoms constitute a syndrome termed "occupational asthenopia". Here "work environment factors and tasks, combined with the ophthalmic characteristics of the subject, may potentially favour the appearance or recurrence of a series of ocular and/or visual signs and/or symptoms". Thus, the term "occupational asthenopia" is more inclusive than more commonly used terms such as eye irritation, visual fatigue visual strain, veiling/disability glare. Indeed, the range of terminology, is potentially a cause of confusion, leading to limited interpretation and collection of relevant data.

Methods

The study was conducted in north and central Italy (mostly in Milan and Rome) between 2010- and 2013. The participating organisatsions were mainly in the finance sector and resource industries. Detailed information about work tasks was obtained from the workers. All measurements were carried out during normal working hrs, i.e. 09.00-17.00hrs.

Detailed measurments of luminance and illuminance were collected with a Hagner Universal Model S2 photometer using the method of Piccoli *et al.* (2004).

There were 4 phases for luminance assessment being; i) operator task analysis, including the identification of objects/ images (occupational targets); ii) determine the OVF - the space that encloses the occupational fixation zones involved; iii) measure luminance and construct isoluminance maps (see Figure 3); and compare luminance ratios in the OVF.

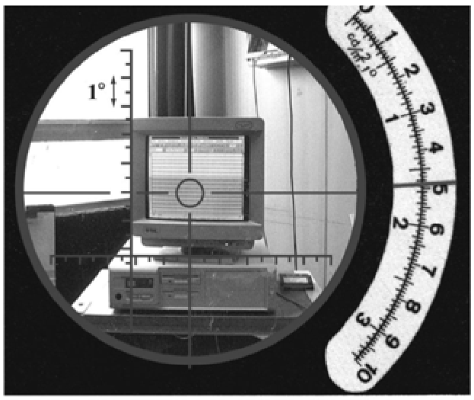

FIGURE 2

A VDU workstation screen from the viewfinder of the luminance meter. The display on the right-hand side gives the luminance reading from the centre of the circle. (Piccoli *et al.*, 2004).

Results

Parameters measured were highly dependent on light fitting position and window location.

The OVF luminance ratios were found to be excessively high (>1:250 cd/m^2) in 19% of workstations, moderately high (1:100-1:250 cd/m^2) in 20% of workstations and considered satisfactory (<1:100 cd/m^2) in 61% of workstations. A summary of the values that exemplify these three conditions at workstations is reported in table 2 and in figures 3 – 8.

TABLE 2

List of 25 of the 100 workstations studied*

Workstation	Company	Luminance ratio	Portion of the OVF concerned
1	A	Moderate	central-left (min# - max = 20/2,500 cd/m^2)
2	B	Moderate	central (min# - max = 40/4,500 cd/m^2)
3	B	High	left (min# - max = 40/10,000 cd/m^2)
4	B	High	central-right (min# - max = 30/12,000 cd/m^2)
5	C	Adequate	(min# - max = 25/300 cd/m^2)
6	D	High	right (min# - max = 20/5,100 cd/m^2)
7	D	Moderate	left (min# - max = 20/3,200 cd/m^2)
8	D	High	right (min# - max = 18/6,000 cd/m^2)
9	D	Moderate	left (min# - max = 22/2,300 cd/m^2)
10	D	Adequate	(min# - max = 45/450 cd/m^2)
11	D	Adequate	(min# - max = 42/300 cd/m^2)
12	D	Moderate	right (min# - max = 24/3,300 cd/m^2)
13	D	High	left (min# - max = 15/4,000 cd/m^2)
14	D	Moderate	Left (min# - max = 24/4,500 cd/m^2)
15	D	High	Central-left (min# - max = 18/5,000 cd/m^2)
16	D	Moderate	Central-right (min# - max = 40/4,000 cd/m^2)
17	D	Moderate	Central-right (min# - max = 40/5,000 cd/m^2)
18	D	Adequate	(min# - max = 22/1,500 cd/m^2)
19	D	Adequate	(min# - max = 45/2,500 cd/m^2)
20	D	Moderate	left (min# - max = 50/8,000 cd/m^2)
21	D	Adequate	(min# - max = 80/4,000 cd/m^2)
22	E	High	central-right (min# - max = 20/4,500 cd/m^2)
23	E	High	central (min# - max = 20/6,500 cd/m^2)
24	E	High	central (min# - max = 50/17,000 cd/m^2)
25	F	Moderate	central (min# - max = 40/6,000 cd/m^2)

**Luminance ratios were deemed excessively high (ratio > 1:250), moderately high (ratio 1:100 - 1:250) or "adequate" (< 1:100). # Inferred average of most significant values within the central portion of the OVF, including screen, keyboard and main devices.*

Illuminance on the working plane ranged from 100-2500 lux and correlated poorly with luminance. In this regard, see figures 3 and 4 where, although illuminance on the working plane is adequate (630/420 lux), luminance levels from windows are very high (up to 10000/12000 cd/m^2). Also in figure 7 it is evident that illuminance levels on the desk (100 to 150 lux) are barely influenced by the high luminance from the window at the left end of the room. Lastly, in figure 8, other than the very high luminance ratio are existing in the operator's OVF (1:340), it is noteworthy that the lamp on the wall is possibly annoying the operator when window luminances are low i.e. in the evening or with venetian blind in use.

Discussion & Conclusion

The problem of visual disturbance in office work is very common. Luminance is the more appropriate indicator of visual disturbances, based on anatomy and physiology.

In order to measure the luminance and luminance ratios in the visual field, a rational method should be used (Piccoli *et al.,* 2004).

Across 100 workstations, there was a poor relationship between luminance and illuminance. Indeed, illuminance ratios ranged from tens of lux (min.) to 2500 lux (max.) with a ratio of 40, a much lower ratio compared to that of

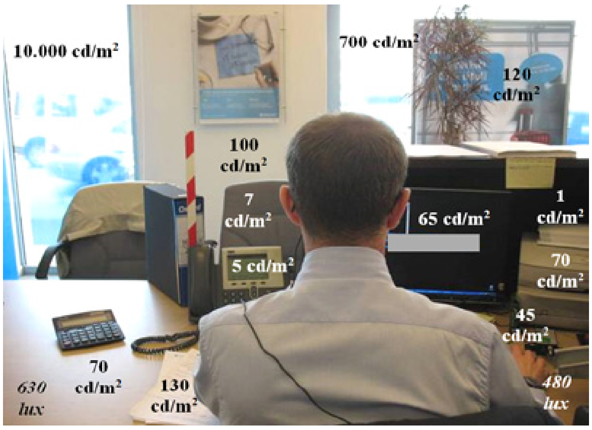

Figure 3 - Workstation 3

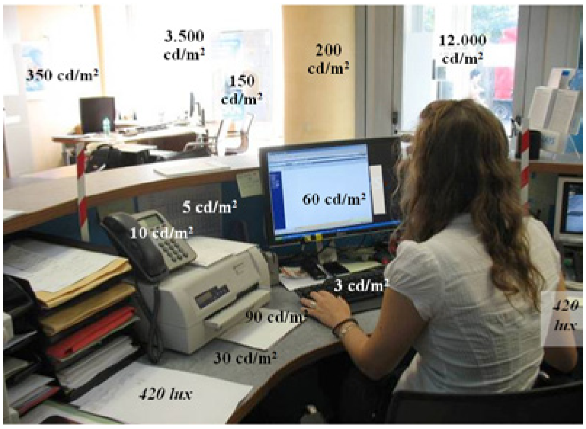

Figure 4 - Workstation 4

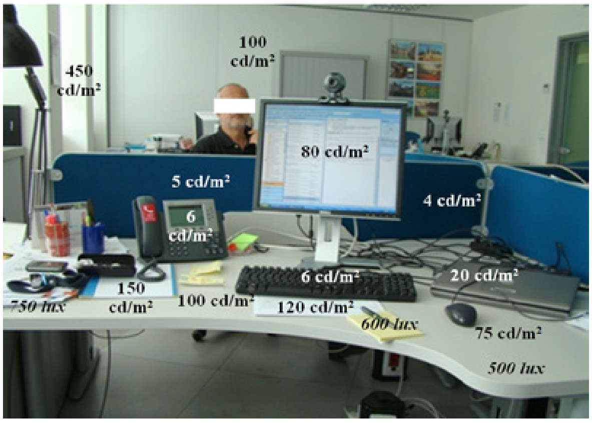

Figure 5 - Workstation 10

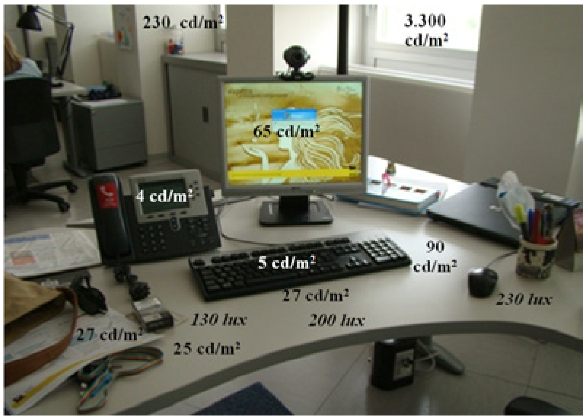

Figure 6 - Workstation 12

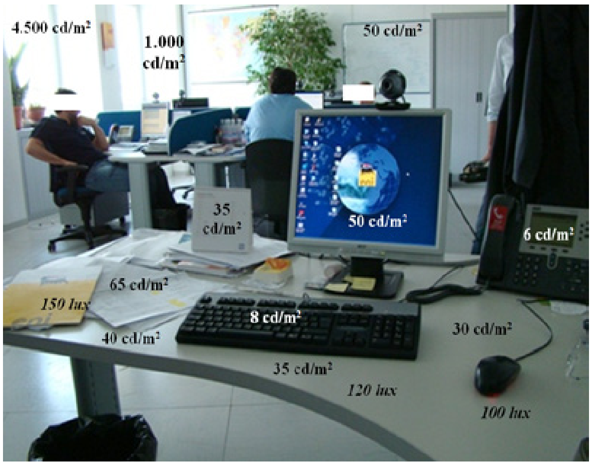

Figure 7 - Workstation 14

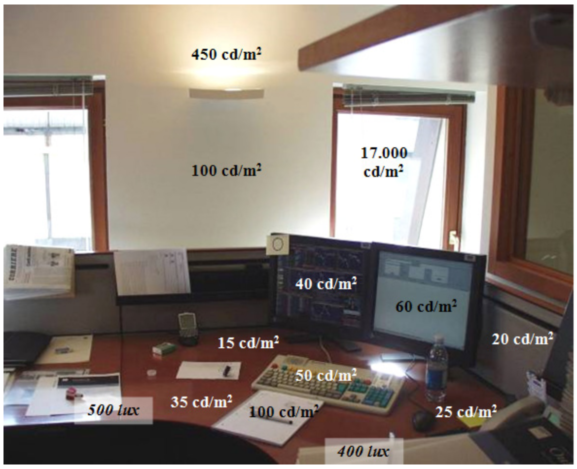

Figure 8 - Workstation 24

luminances. Moreover, we found that glare from natural light was not always well controlled even though blinds are available. This may be attributable to poor maintenance, disagreement among operators on blind use and, particularly in open spaces/big offices, low natural light at working stations distant from windows.

Interestingly, utilisation of task lighting was uncommon, but this could be effective, particularly for aged operators, in controlling illuminance on documents, keyboard, etc. without increasing the artificial lighting.

Consideration of workers' lighting-related visual disturbancies and analysis of luminance leads to better design of lighting systems and workstation layout. Lighting risk assessment carried out by the measurement of luminance is a better diagnostic process than that by illuminance alone. Luminance measurements can be very precise and detailed in showing where lighting conditions are problematic within the operator's OVF. Finally, luminancies can be very useful in re-design of lighting systems at workstations.

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