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Experimental study of the ocular behaviour in office workers as a visual comfort indicator in glare risk situations

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Abstract: The daylight impact on the visual environment is fundamental on visual display terminal work (VDT). Visual performance and visual comfort should be considered for equal. The study (n=16) was performed at the experimental lighting laboratory. Office work with VDT was evaluated using STROOP task in two orientations: (with/without solar presence in the visual field). Our hypothesis states the existence of a relationship between ocular behavior and visual comfort of workers. An eye-tracker was employed in order to record the ocular gestural parameters: blinks, direction of gaze, eye aperture (Degree of eye's openness) and pupil size, which were correlated with the vertical illuminance at the eye. Visual comfort was assessed with Glare Sensation Vote. Results indicate a strong negative linear correlation between eye illuminance and the degree of eye's openness in the direct sunlight scenario (p=-0.636; s=0.008) and in diffuse light scenario (p=-0.661; s=0.005), that could be the main predictor of visual discomfort. This experiment allowed us to explore eye behavior patterns that could be visual comfort indices under glare risk situations.

Keywords: visual comfort, visual performance, ocular indicator, glare.

Estudo experimental do comportamento ocular em trabalhadores administrativos como um indicador de conforto visual em situação de risco de encadeamento

Resumo: O impacto a luz do dia no ambiente visual é fundamental para o trabalho no Ecrã de Visualização de Dados (EDV). Desempenho visual e conforto visual devem ser considerados em igual. O estudo (n = 16) foi realizado no laboratório experimental de iluminação. O trabalho de escritório com EDV foi avaliado utilizando a tarefa de Stroop em duas orientações: (com / sem presença solar no campo visual). A nossa hipótese afirma a existência de uma relação entre o comportamento ocular e conforto visual dos trabalhadores. Um "eye-tracker" foi desenvolvido para gravar os parâmetros gestuais oculares: pestanejar, direção do olhar, abertura dos olhos (Grau de abertura do olho) e tamanho da pupila, que foram correlacionados com a iluminância vertical no olho. Conforto visual foi avaliado com a escala de sensação de encadeamento. Os resultados indicam uma correlação linear negativa forte entre a luminosidade dos olhos e do grau de abertura de olho no cenário de luz solar direta (p = -0,636; s = 0,008) e no cenário de luz difusa (p = -0,661; s = 0,005), que poderia ser o principal preditor de desconforto visual. Esta experiência permitiu-nos explorar padrões de comportamento do olho que poderiam ser os índices de conforto visual em situação de risco de encadeamento.

Palavras-chave: conforto visual, desempenho visual, indicador ocular, encadeamento.

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1. Introduction

In interior lighting design, the use of daylight can produce major benefits for users. Among them, contributing to the functioning of the circadian system (Webb 2006), it improves the quality of a room lighting and produces a higher tolerance to glare situations than an artificial light source (Chauvel et al. 1982). However, under uncontrolled lighting conditions, visual discomfort might occur.

Visual discomfort has a number of distinctive features. First, visual comfort is characterized by large individual differences, experience, expectations and attitudes. Second, visual discomfort is dependent on context. Third, the determinants of visual discomfort cover the whole visual field. There are many different aspects of lighting that can cause visual discomfort: Insufficient light to perform a task, lack of uniformity, glare, veiling reflections, shadows, and flicker (Boyce 2010).

Natural light, controlled, has positive impact on human health and performance, as well as on thermal and lighting efficiency of constructed spaces (Boyce 2003). However, glare often correlates with uncontrolled sunlight through high or non-uniform luminance distribution within the visual field. Lighting conditions in a room lit with natural light can change dramatically between the outside and inside in presence of sunlight. The human visual system has physical, neural and photochemical mechanisms to adapt to those changing lighting conditions (Rea 2000) in a wide range of 10^{10} orders of magnitude; however these mechanisms can handle variations of 10^3 steps at a time. Glare is caused by an unsuitable luminance distribution, or by high luminance contrasts within the visual field (CIE 1987). Disability glare is the effect associated with a reduction in visual performance due to the masking effect caused by light scattered in the ocular media which produces a veiling luminance over the field of view (Stiles and Crawford 1937; Vos 2003).

Discomfort glare refers to the sensation perceived which is not necessarily tied to a reduction in visual performance. It is a distracting effect of peripheral light sources in the field of view. Veiling glare occurs when the reflection superimposes itself upon a visual target and causes difficulty in seeing that target. Due to the reflection, the luminance of the object to be seen is intensified by the extra luminance which results in reducing the contrast and hence the visibility of the object.

The workspaces evaluated in cities with sunny climates show the presence of windows exposed to uncontrolled direct sunlight without adequate light control strategies. Two common situations are found instead 1- daylight from windows blocked by users due to the potential risk of glare 2- shading devices and elements located and designed with morphological, symbolic or aesthetic criteria and placed without any verification of solar control functionality (Villalba, Pattini, and Córica 2012).

The uncontrolled sunlight in office workspaces produces undesirable effects on users' vision, especially while using VDT (visual display terminal) (Grandjean 1984), and it was demonstrated that high tolerance to glare increases eyestrain level (Smith 1979). The most frequent eyestrain symptoms are irritation of the eyes, evident as inflammation of the eyes and lids; breakdown of vision, evident as blurring or double vision; and referred effects, usually in the form of headaches, indigestion, giddiness, etc. (Boyce 2010).

Pupil size responds to changes in retinal illumination by constriction and dilation. The pupil diameter varies between 2 to 8 mm in young people. It is dependent on the effects of luminance, size of the adapting field, age of the observer, and whether one or both eyes are adapted (Watson and Yellott 2012). Although this diameter variation leads to a luminance variation of only 16:1, studies have associated glare with certain pupil fluctuation (Hopkinson 1957; Fry and King 1975). Excessive light in the eye area produces changes in the activity of facial muscles around the eye (Berman et al. 1994; Binda and Murray 2013). Constant shifting between intraocular and extra ocular muscles in attempts to obtain a clear image, and of increased intraocular pressure caused by frowning or neuro-hormonal action (Smith 1979).This ocular mechanism could produce eyestrain. However, those studies were mostly done under artificial lighting conditions.

The very few studies we found that investigated the relationship between view direction and visual comfort in office settings indicate that view direction is mostly aimed at the work area or a moving stimulus. If the person takes a break from the computer, his or her vision is directed at the window (Hubalek and Schierz 2004; Sarey Khanie et al. 2009). However in a situation of visual discomfort there is a displacement of the view direction avoiding the glare source (Luckiesh and Guth 1949).

When the view outside is possible and there is a pleasant contemplation of a landscape through a window, there is greater tolerance to glare (Tuaycharoen and Tregenza 2007); on the contrary harder tasks are associated with less tolerance to glare (Sivak et al. 1989).

Inadequate lighting conditions reduce visual comfort. The studies on discomfort glare are mainly subjective and based on light measurements combined with conventional psychophysical procedures (Boyce 2003) to obtain standard glare prediction indices. Evaluating glare in complex scenes may require fundamental changes to currently accepted glare models (Clear 2013).

This paper tests the hypothesis that there is a relationship between ocular behavior (blink, direction of gaze, eye aperture, and pupil size) and visual discomfort.

2- Material and methods

The study was performed at the experimental lighting laboratory at CCT-Mendoza, Argentina (latitude 32°53´S; longitude 68° 52´ O) (Figure 1-2). Its orientation can be changed by rotating the structure thanks to a central axis under its floor which allows a wide range of sun altitude and azimuth to be studied, quite independent of the season. The laboratory has two experimental sections: the first one has measuring equipment (reference room), and the other (test room) is equipped with one workstation (a desk, an office chair, and a computer) in which the volunteers performed the required task with a 15.6 LED Screen Lenovo B570 Notebook (keyboard reflectance=0.327). The interior has white walls and it is decorated as an actual office. The workplace was next to the window and our participants were seated 0.5 m away from the window, facing it.

The two sections are characterized by identical reflectance (r): rwall = 0.91, rceiling = 0.06, rfloor = 0.07 and geometrical features (1.75 m wide, 3.4 m deep, 2.7 m high). The only light source is the window, a 1.2 m wide, and 1.14 m high glass area with an apparent size of 1.78 sr. The window was a 4 mm single-glazed clear glass with a light transmission of t = 89%, u-value of 5.8 W/m2°C and a heat gain coefficient of 0.84. No solar shading devices were attached to the window. A low density built surrounding with scarce vegetation allowed no obstructions from the window and a full access to sunlight.

Figure 1: Picture of the experimental lighting laboratory.

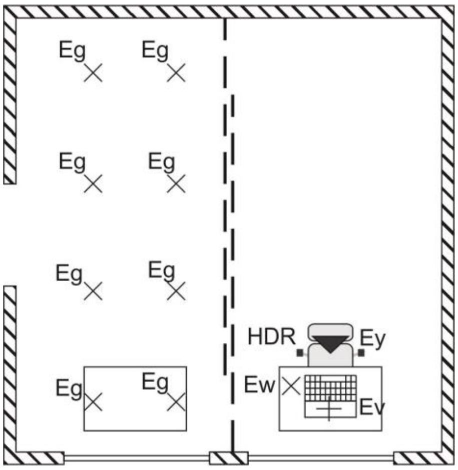


Figure 2: Plan of experimental lighting laborator): (Et) Horizontal Task Illuminance. (Ey): Vertical Eye Illuminance. (Ev): Screen Vertical Illuminance. (Ew): Window Vertical Illuminance. *(Eg): Horizontal Grid Illuminance*

The methodology for data collection can be divided into three main stages: (1) Physical and photometric data (independent variables), (2) eye and gestural variations (dependent variables) and (3) participant´s subjective response (dependent variables).

2.1 *Photometric, environmental and ocular data*

Temperature and humidity: we monitored these variables throughout the experiment, at the beginning and the end of each trial with a LMT 8000 environmental measurement device. Trials performed outside the 30 +/- 3 °C range were removed from the sample.

Lighting Levels: We monitored the indoor illuminance on the work plane in the reference room with a LMT pocket lux 2 (range 0.1 to 120000 lux,). We defined the following metrics:

We measured every 10 minutes the following photometric variables: Horizontal illuminance where the paper task was performed (Et), Vertical illuminance at the eye (Ey), Vertical illuminance at the center of the computer screen (Ev) and Vertical illuminance at the center of the window (Ew).

Illuminance Uniformity and mean illuminance on the work plane: Eight measuring points at regular distances formed a grid at 0.85 m from the floor. This allowed us to calculate the mean illuminance on the work plane and illuminance uniformity:

$$E_{min} \geq E_{mean} / 2 \qquad (1)$$

Where: E_{min}: Minimum Illuminance; E_{mean}: Mean Illuminance

Ocular measurement: to quantify the indicators previously described (blink, direction of gaze, eye aperture and pupil size) we developed a visible range eye-tracker (Figure 3). This eye-tracker was constructed by our team at the Human and Built Environment Laboratory (HBEL) and consists of two cameras operating in the visible spectrum, in order to register daylit environmental conditions characterized by high and uncontrolled lighting situations. The camera has a 720x480 pixels resolution and 30 frames per second. The capture is in real time. One of the cameras records the eye movement and the other one records the observer´s visual field. The captured scenes are processed with the open source Starburst® algorithm, a free software redesigned to operate in the visible spectrum (Li, Winfield, and Parkhurst 2005). A calibration stage is needed, consisting in briefly fixating sequentially in a nine point grid, in order to link the eye recording with the scene recording.

Participant´s subjective response: The assessment method chosen for Discomfort Glare was semantic differential scaling using glare sensation vote (GSV) (Iwata and Tokura 1998). This estimates the glare sensation as a function of the time the subject could stand the sensation of discomfort. The criteria of this ordinal scale are: Unnoticeable Glare (UG), Just Perceptible (JP), Just Uncomfortable (JU); Just Intolerable (JI). A digital form that included a definition for each point, presented the scale on the screen. This scale has been widely used since its introduction (Chauvel et al. 1982; Osterhaus and Bailey 1992).

Participant´s ocular response: Visual demand indicators were measured while working at the VDT: they performed a divided attention Stroop task (MacLeod 1991) while performing a Working Memory Span Task, that requires both the storage and the processing of information. This task design includes the essential features of office work with computers: high working memory demands (Wästlund 2007) and divided attention (Hashizume, Kurosu, and Kaneko 2007; Rodriguez and Pattini 2012). Data collection lasted for 180 seconds, the estimated realization time for the Stroop task.

The Stroop task presents stimuli to participants in which the relationship between meaning and color has been manipulated so that it is congruent (the word RED presented in color red) or incongruent (the word BLUE presented in color green), resulting in a delay in the color processing of the word, increasing reaction time and promoting errors. This semantic interference is called Stroop effect and its magnitude is an indicator of selective attention by requiring subjects to respond selectively to a particular type of information while ignoring other information that competes for the realization of a goal. The robustness of the test has earned its name as the “gold standard” of attentional measures (MacLeod, 1991). This primary task was presented in the PVD through PsychoPy open source software. Stimuli (RED, GREEN and BLUE) were presented in the center of the PVD, in Arial 16.point font colors (red, green and blue). The amount of congruent and incongruent stimuli was balanced and text/color combinations were randomly presented. The response of the subjects was recorded using the computer keyboard. The training consisted of four blocks of 12 repetitions, while the experimental session consisted of eight blocks of 12 repetitions.

Data measured:

Blink frequency: The functions of blinking are ocular globe protection against external agents such as light, heat, cold, dust, and the distribution of the tear film, wetting ocular surface and removing foreign particles.

The normal blink rate is 15 blink/min (Karson et al. 1981). These values could change when people is performing a task. These differences are due to the influence of visual and environmental conditions (Monster, Chan, and O’Connor 1977; Anon 2000). The eye-tracker frames were post processed with Inkscape, an open source vector graphic editor, in order to find the numbers of blinks. First, we processed the eyes' videos, obtaining a blinks mapping (Figure 4). Then we analyzed the eye, frame by frame, to perform a manual count of the blinks number.

Figure 3: Eye-tracker

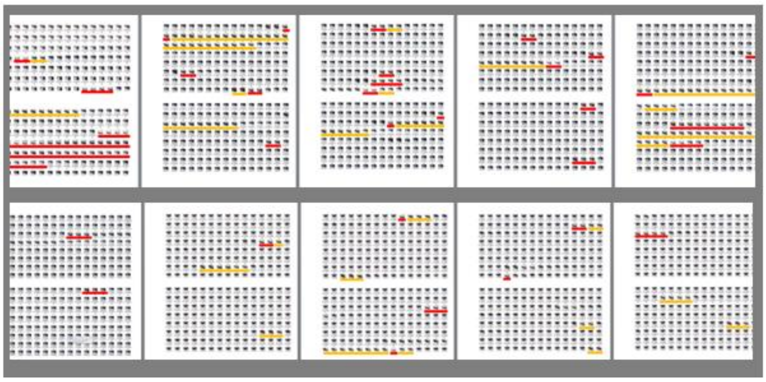


Figure 4: Blinks frequency mapping (red interval are complete blinks and yellow intervals are incomplete blinks)

Direction of gaze: we registered the gaze distribution in relation to the glare source using a specific built-in capability of Starburst software. This software can measure the user's eye movements from videos recorded with the eye tracker cameras.

To calculate the corresponded between the eye position and the scene, the user should see a gridding of 9 points, process called calibration. After calibration it can be establish a relationship between the direction of gaze and the scene from a second-order polynomial mapping. The average error in terms of visual angle is about 1 degree after calibration.

Eye aperture: The aim is to determine the degree of muscle contraction around the eyes to reduce light income. We used a method to judge open/closed eye based on the degree of openness (Tsao 2008).

First, we used a mask to find the center of pupil. We took the pupil center coordinates (xp, yp) as a reference point and then we searched for the two largest difference values upward and downward along the y-axis direction.

In order to find the interference between the pupil and eyelid, we shift the xp position to set two new calculating points (with a margin of 2 pixels) as:

$$xpl = xp - 2, \quad xpr = xp + 2 \qquad (2)$$

We calculated the largest difference values upward and downward along the y-axis direction for both referencing points individually. We obtained four points: P_{l_up}, P_{l_down}, P_{r_up}, and P_{r_down} where P_{l_up} is the position which has the largest difference calculated from the left reference point upward along the y-axis, P_{l_down} is the position which has the largest difference calculated from the left reference point downward along the y-axis, P_{r_up} is the position which has the largest difference calculated from the right reference point upward along the y-axis, and P_{r_down} is the position which has the largest difference calculated from the right reference point downward along the y-axis. We selected the higher y-axis position as the top-detected point and also the lower y-axis position as the bottom-detected point. Finally we calculated the distance L between the top-detected and bottom-detected points and defined it as the eye's height.

Because the size of eyes is different among individuals and it also varies with the relative distance between the camera and the subject's face, we determine the degree of eye openness by the ratio of eye's height which is described as:

$$\text{Degree of eye's openness} = L/\ L\text{max} \qquad (3)$$

Where L is the height of the eye in current frame and Lmax is the greatest height of the eye when it is fully open (Figure 5).

A threshold value is established for judging whether the eye is open or closed: if the ratio is smaller than 0.2, the eye in this frame is defined to be closed; otherwise it is defined to be open (figure 6).

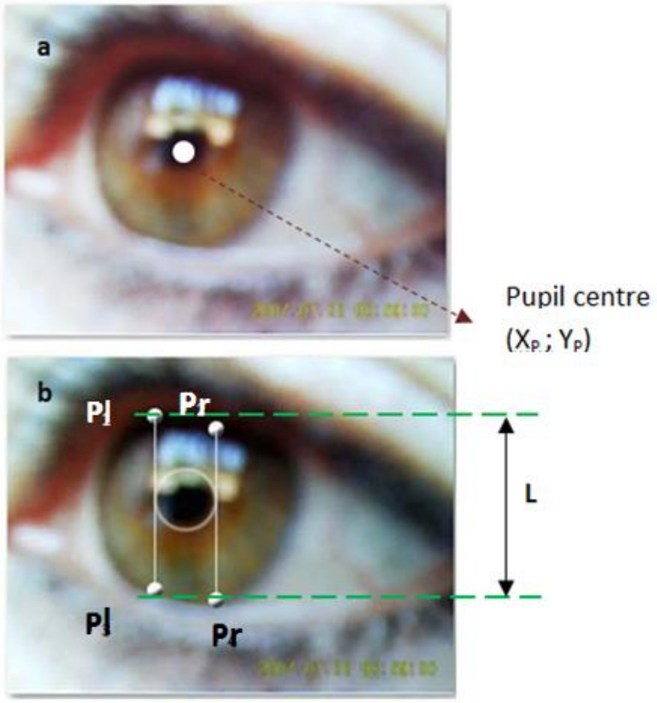


Figure 5: a- pupil center b- L obtention

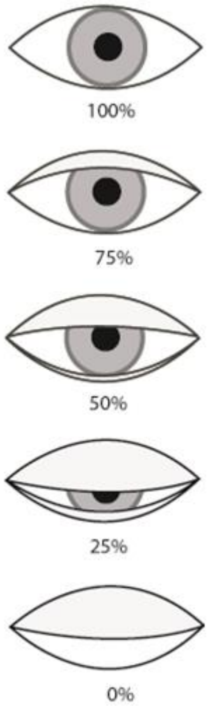
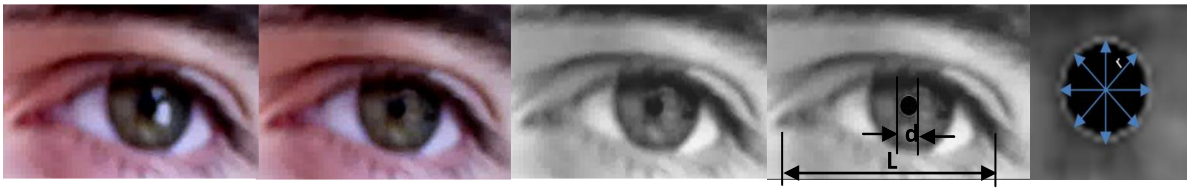


Figure 6: percentage of eye opening

Pupil size: Average and deviations pupil size value was obtained every 10 s. We used the method proposed by Bianchetti and Comastri (2008). This method consists in an eye image processing in order to define the pupillary region. First, we remove the image noise (shadows, light reflections). Then we performed a contrast image correction in gray scale to make it easier to process. Then, to detect the pupil edge, we found a threshold level in order to differentiate the iris and the pupil. This threshold level should be greater than the gray level of the pupil and less than the gray level of the iris. After the edge detection, the pupil diameter is calculated from the length of the eye ratio (mm). For greater precision, we measured six pupil diameters. The final diameter is the mean diameter (figure 7).



1 Front view of the eye *2 Noise elimination* *3 Contrast correction* *4 Pupil diameter determination and pupil mean diameter*

Figure 7: procedure to find pupil diameter

2.3 Experimental Procedure

In this study we attempted to reproduce two typical office situations with sunny climate, in which the presence of highly glazed office buildings increases the probability to be disturbed by glare (Byrd 2012).

In both scenarios, luminance contrast was high above the usual recommendations. A number of extensive studies into daylit spaces (Parpairi et al. 2002) concluded that the luminance ratios in real-world offices were far from the recommended 3:1 & 10:1 ratios, yet users were still satisfied with the lighting conditions in a number of different luminance distributions. With regard to the 1500 cd/m2 recommended maximum luminance; an overcast sky as seen through an office window can have luminances higher than 10.000 cd/m2.

For this first study, two window scenarios were selected: 1- with presence of direct sunlight. 2- with presence of diffuse light. The sunlight scenario imposed more visual demands due to the presence of the high luminance, large area lighting source, while the diffuse light one was a less demanding control scenario (Figure 7). Data collection was in November 2012, and December 2013 in the morning (between 9 and 10:30).

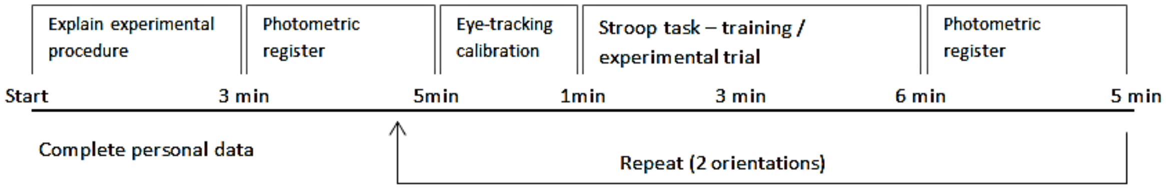


Figure 8: experimental procedure

Figure 8 shows the sequence of activities performed during the experiment, and the approximate time each stage demanded. In its upper part the graphic shows the actions done by the experimenters and the tasks required to the volunteers (V). Once inside the laboratory, each volunteer was asked to take a sit, then the experimenter explained the experimental procedure and ask him to fill in a form with basic personal and demographic data. Meanwhile the experimenter registered the initial environmental and photometric data. Then the Stroop task training began followed by the first experimental trial, where the Stroop task was performed simultaneously with the memory task. Once both tasks were completed, the experimenter recorded the final environmental conditions. Finally, the experimenter prepared the following scenario, giving the volunteer a five minute break.

3- Results and discussion

3.1 Physical and photometric data collection

A total of 4 men and 12 women (n=16) ranging from 22 to 38 years participated in this experiment.

Table 1 shows mean values and standard deviation of temperature, humidity, and horizontal illuminance on the working plane, vertical illuminance at the eye and uniformity values.

Table 1 : Photometric and environmental data

	Direct sunlight		**Diffuse sunlight**	
	Mean	SD	Mean	SD
Mean Temperature (Cº)	31.62	1.81	31.01	1.63
Mean Humidity (%)	34.73	8.56	34.89	9.65
Mean Ey (eye) (lux)	24438.12	17888.43	2161.81	256.64
Mean Ev (background) (lux)	3023.50	1009.97	508.93	201.99
Mean Et (workplane) (lux)	11519.56	2641.82	1910.62	2030.69
Uniformity	(46225 > 32824.9) NON-UNIFORM		(1467 > 1095) NON-UNIFORM	

Workplane Horizontal Illuminance levels were high above the usual VDT recommendations: an international comparison identified large variations in VDT work recommended Et , with 500 lx as the most frequent value (Pattini and Kirschbaum 2007) .

The paired t-test performed showed a statistically significant differences between direct sunlight (24438.12 lx; SD=17888.43 lx) and diffuse sunlight (2161.81 lx; SD=256.64 lx) scenarios in vertical illuminance (t=-4,984; p=0.00). The paired t-test performed showed in Workplane Horizontal Illuminance (t=-10,146; p=0.00) and in background Horizontal illuminance (t=-9,679; p=0.000).

Other environmental factors monitored were temperature and humidity. Both scenarios had similar mean temperature and humidity. The paired t-test performed showed no statistically significant differences between direct sunlight and diffuse sunlight scenarios in temperature (t=1.574; p=0.140) and humidity (t=1.723; p=0.120).

3.2 Blinks frequency

We measured the number of blinks in both scenarios. In direct sunlight scenario the number of blinks/min was M = 27.07, SD =8.07. In diffuse light scenario the number of blinks was M= 19.00, SD= 8.01.

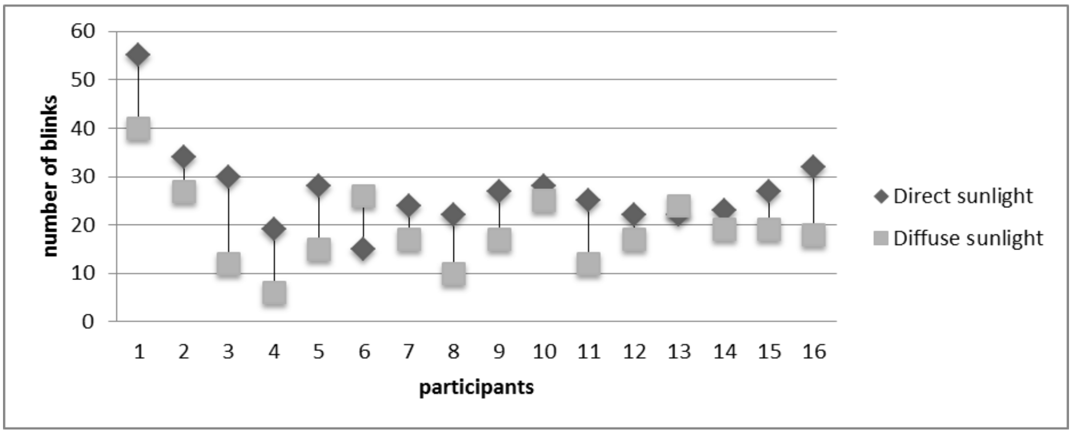


Figure 9: Number of blinks per minute of the six participants in both situations

We performed a paired T test and we observed that the number of blinks was significantly higher in the orientation with the presence of direct sunlight (t=-4.436; p=0.000) (Figure 9). We did not found a lineal correlation between vertical eye illuminance and the numbers of blinks neither in the direct sunlight scenario (p= -0.150; s=0.571) nor diffuse light scenario (p= 0.026; s=0.924).This non-significant correlation could be caused by attentional and personal factors that increase the number of blinks besides lighting. Such as fatigue, cognitive demands and mental workload (Anon 2000).

3.3 Direction of gaze

During the task execution (table 2), the vision is mainly focused on the screen (diffuse light scenario M=95.93%; direct sunlight scenario M=96.75%), while the number of times that participants look the keyboard is smaller (diffuse light scenario M=3.50%; direct sunlight scenario M= 2.75%). Finally vision is focused outside the task less than (diffuse light scenario M=0.56 %; direct sunlight scenario M=0.50%) (Figure 10). This ocular behavior could be explained by the high demands the task imposed on the subject, requiring them to keep the view on the VDT. Eventually they also looked at the response keys in the keyboard to achieve a good performance and avoid input errors.

We performed a paired T test and we observed no significant differences between the two orientations: screen movement (t = 0.605; p = 0.554), keyboard movement (t = -0.679; p = 0.508) windows movement (t =-0.155; p = 0.879).

Table 2: Direction of gaze during task performance

	Direct sunlight		Diffuse sunlight	
	Mean	SD	Mean	SD
screen	96.75%	4.64%	95.3%	6.11%
keyboard	2.75%	4.29%	3.55%	6.07%
Window	0.50%	1.095%	0.56%	1.03%

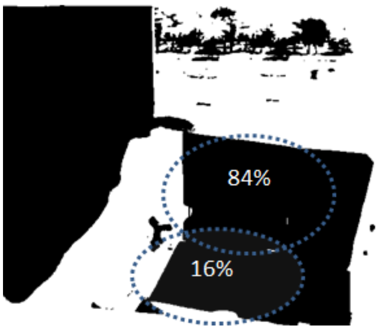


Figure 10: Direction of gaze

3.4 Eye aperture

We performed a paired T test on this data. The eye aperture is significantly lower in the orientation with direct light, compared with the diffuse light orientation (t = -13.294; p = 0.000) (Table 3). We found strong negative lineal correlation between vertical eye illuminance and eye opening in the direct sunlight scenario (p=-0.636; s=0.008) and in the diffuse light scenario treatment (p=-0.661; s=0.005). We estimated the effect size (eta squared) for this variable. The proportion of variance in vertical eye illuminance explained by the eye aperture is in direct light scenario (0.95) and in diffuse light scenario (0.97).

This indicator could be used as proxy to predict light changes in a dynamic environment (Figure 11).

Table 3: ocular measures

Subject	Total height(mm)	Direct sunlight		Diffuse sunlight	
		Height (mm)	Degree of eye aperture	Height (mm)	Degree of eye aperture
Mean	12.1	8.72	0.692	11.94	0.979
SD	1.99	1.81	0.801	2.09	0.023

Figure 11: participants' eye aperture

We performed a paired T test on this data. The eye aperture is significantly lower in the orientation with direct light, compared with the diffuse light orientation (t = -13.294 p = 0.000) (Table 4). We found strong negative lineal correlation between vertical eye illuminance and eye opening in the direct sunlight scenario (p=-0.636; s=0.008) and in the

3.5 Pupil size

The pupil size is significantly smaller in the direct light orientation, in relation to the diffuse light scenario. (t = -6.022, p = 0.000) (Table 4). We did not found a lineal correlation between vertical eye illuminance and eye opening in the direct sunlight scenario (p=-0.309 s=0.244) and diffuse light scenario (p= -0.273; s=0.307).This non-significant correlation is due to the limitation of the pupil adaptation mechanism: it can only limit the entrance of rays of light in a range of 1.5 orders of magnitude. The basal level in illuminance in both scenarios is high above the pupil adaptation mechanism capabilities. In our experimental conditions this pupil size is not an adequate ocular indicator, but in lower illuminance condition it might be a possible indicator. We estimated the effect size (eta squared) for this variable. The proportion of variance in vertical eye illuminance explained by the pupil size is in direct light scenario (0.80) and in diffuse light scenario (0.89).

Table 4: mean and SD pupil size values

Subject	**Direct sunlight**		**Diffuse sunlight**	
	Mean	SD	Mean	SD
Pupil size	3.64	0.29	4.64	0.64

3.6 Participant´s subjective response

Table 5 shows GSV subjective responses. There was a different glare sensation from windows in VDT reading tasks between scenarios, without a perceptible glare in the diffuse sunlight scenario, and a glare sensation mostly described as just disturbing in the direct sunlight scenario. The Wilcoxon test confirmed that glare sensation when reading on screen and paper was less satisfactory in the direct sunlight treatment (p.value <0.001). The proportion of variance in vertical eye illuminance explained by the GSV subjective responses is in direct light scenario (η2=0.90) and in diffuse light scenario (η2=0.75).

Table 5: Glare Sensation Vote response frequencies

	Direct sunlight	**Diffuse sunlight**
	VDT Reading Task	VDT Reading Task
mean	3.25	1.5
median	3	1.5
mode	3	1-2

Scale: (1=Unnoticeable Glare, 2=Just Perceptible, 3= Just Uncomfortable; 4=Just Intolerable)

Our data suggests that horizontal illuminance fails to predict people’s reaction to a glare source despite its role as a visual performance predictor (0.084; p.value=0.379). Vertical illuminance at the eye is an easy to use proxy of the visual system adaptation status (Wienold 2009) and correlates better with glare sensation in a wide range of sunlight exposure levels (0.467; p.value < 0.001).

4- Conclusion

In this study we investigated the ocular behavior while performing clerical tasks. This task has high memory and divided attention demands. It was performed in two lighting conditions: one with diffuse natural light and the other with direct sunlight as a glare source in the field of vision.

Our results showed higher discomfort due to glare in presence of the large area glare source in presence of direct sunlight ($\eta 2=0.90$) than in its absence. These results were quantified by ocular indicators (blinks, eye aperture and pupil size).

The number of blinks, eye aperture and pupil size showed differences in both situations (direct sunlight / diffuse light). These ocular behaviors could be indicators of visual discomfort. By contrast there were no variations in the direction of gaze between the two situations. Last one ocular behavior could be explained by the high demands the task imposed on the subject, requiring them to keep the view on the VDT.

We explored three possible indicators of visual discomfort (blinks, eye aperture and pupil size). We conclude that, on the one hand numbers of blinks are not fully explained by light variation. Blinks also owe their presence to other personal and behavioral aspects (Wolkoff et al., 2003). On the other hand, although pupil size quit sensitive to illuminance variation, in our experiment it was not a good lighting level indicator. Since this mechanism can only reduce the light intensity in a range of 1.5 orders of magnitude. A range that was largely exceed in our experimental condition in both situations (direct sunlight / diffuse light).

Finally, we found a strong negative linear correlation between vertical eye illuminance and eye aperture in the direct sunlight scenario ($p=-0.636$; $s=0.008$) and in the diffuse light scenario ($p=-0.661$; $s=0.005$). This could be the ocular indicator that best predicted the variation in high lighting levels. Considering the ocular mechanisms have limitations for lighting regulation, several of them should have complementary functions, to improve visual task performance.

In this first work we found an indication of some patterns of ocular behavior that could be visual comfort indices in glare risk situations. The eye aperture is a promising objective indicator for future researches. To be used in a daylight range of typical sunny climates.

In order to predict the uncontrolled sunlight in office, avoiding undesirable effects on the users' vision, especially in the use of VDT.

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