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A large variability in response is usually found when assessing discomfort glare by semantic differential scaling. This issue may be addressed by considering the individual's tolerance to glare, so we designed an experiment to describe the differences in glare sensation vote caused by a simulated window while glare-sensitive and glare-insensitive subjects performed a computer task. The luminance and size of the window had the same statistically significant effect on glare sensation for both groups. However, when occasionally looking directly at the glare source, glare-sensitive people experienced more glare than insensitive persons with a relative risk of being disturbed that varied from 2.70 to 6.75. Our data suggest that the glare threshold should be redefined to consider glare tolerance to achieve a glare-free, inclusive visual environment.

1. Introduction

The electronic office, introduced in the 1980s, raised new concerns in lighting design, mainly the prevention of disability or discomfort glare for visual display terminal (VDT) operators.[1,2] The CIE defines glare as the particular condition that could cause discomfort or could reduce visual performance, i.e. the visibility and the capability to resolve details and objects, due to an unsuitable luminance distribution, or by high luminance contrasts within the visual field.[3] The effect associated with the reduction of the visual performance, but not necessarily coupled with discomfort, is defined as disability glare, whereas the effect associated with discomfort but not necessarily tied with the possible reduction of visual performance is defined as discomfort glare. A large body of knowledge has been developed around the assessment of visual comfort associated with discomfort glare indoors from electric or natural light sources.[4]

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2. Theoretical framework

Natural light, when controlled, has a positive impact on human health and performance, as well as on the thermal and lighting efficiency of built spaces.[5] It is also preferred as a light source and provides a view out.[6,7] If glare from windows is avoided, power consumption is reduced and lighting quality is improved. These considerations are part of lighting quality, which meets economic requirements but also psychological and biophysical needs.[8–10] These advantages, related to the presence of daylight in the working area, make this illumination system the one favoured by designers and engineers. However, glare often correlates with daylighting through high or non-uniform luminance distributions within the visual field or high

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contrast of luminance between the window and its surrounds. Studies have demonstrated that discomfort glare depends on the glare source's position and size, as well as on the part of sky seen through the window. For computer tasks, the disadvantage could be caused by both veiling glare and a high contrast between the luminance of the background and that of the VDT.

Most of the research involving discomfort glare has been done in experimental chambers using one of two primary data collection techniques. This is true for the study of glare from electric light sources as well as from natural sources.[11–18] The first technique is a method of adjustment in which the subject is asked to adjust the brightness of the background so that the glare source is at the borderline between comfort and discomfort.[19] The second technique is semantic differential scaling, where the subject is shown one stimulus and must rate it on a particular scale.[20] Jacobs et al.[21] compared both methods for assessing discomfort glare and found that semantic differential scaling was more reliable and showed less variation across subjects.[21] Based on that finding we chose the differential scaling approach in this experiment.

Despite the obvious advantage of more control in a laboratory environment, there are several disadvantages in this approach. Nazzal[22] lists the difficulties in these studies; an artificial window is a large and stable source of luminance, while an actual window is characterised by its non-uniformity. The psychological differences between their visual content are also evident, with different glare sensations depending on the landscape.[7,23] Further, natural light has an inherent dynamism; sky conditions characterised by intensity, distribution, colour temperature and spectral content all vary with time.

In the past, little attention has been given to the evaluation of discomfort glare from bright areas surrounding a work task, although such situations frequently occur in daylit spaces, particularly offices.[24] In actual VDT work there are visual tasks (monitor and paper) and the glare source might be at any position in relation to the task. Osterhaus and Bailey[25] conducted an experiment to determine the effect of large area sources on glare sensation in a VDT context. They had a glare source occupying a substantial part of the visual field while the subjects performed a VDT task.[25] They enumerate the limitations of their experiment; while the task could be moderately representative of real tasks, the colour temperature, size and luminance uniformity of the window were limited and not necessarily representative of actual office conditions. Further, the dynamism of the natural source in terms of luminance and its spectral content was not considered. Also, the exposure to the experimental condition was relatively brief.

One of the challenges in assessing discomfort glare is the large variation of responses normally found when comparing individual subjects.[26] Luckiesh and Guth found[26] a 5:1 luminance variation when subjects adjusted the luminance to indicate their borderline between comfort and discomfort relative to their adaptation luminance.[19] In another experiment conducted in a cubicle supplied with a variable luminance glare source operated by a manually controlled dimmer, there were large differences between subjects for each glare criterion and certain differences emerged between groups, encouraging further research in order to understand why people are sensitive to glare and other aspects of the physical environment. Osterhaus and Bailey[25] found that their least sensitive subject required approximately a 100-fold increase in luminance to arrive at the same subjective glare rating as the most sensitive subject when asked to adjust the luminance of a glare source surrounding a computer screen in order to achieve the same glare rating.

In addition, responses of individual subjects were often inconsistent when assessing the same situation. Yun et al.,[27] while studying the influence of window views on the subjective evaluation of discomfort glare, also found wide variations in the discomfort glare evaluation of their subjects.

Although this variability might never be eliminated we believe it could be mitigated by considering the individual's tolerance to glare, rating it systematically in a controlled environment. We designed an experiment to describe and understand the differences in glare sensation between glare-sensitive and glare-insensitive subjects.

3. Material and method

The experimental design for this study was a factorial one, with three factors at two levels, resulting in eight randomised treatments. In some of them the source would theoretically act as a visual stressor causing discomfort glare while in the others no discomfort glare was expected.

3.1. Factors

The first factor examined was luminance (*L*). By definition, a high luminance or high contrasts of luminance in the visual field cause glare.[28] In clear sky conditions with the sun present in the visual field, the luminance can reach values higher than 10^5 cd/m^2 near the solar disc.[29] The human visual system operates over a wide range of light environments, from starlight (3×10^{-2} cd/m^2) to a clear sky (5×10^4 cd/m^2), as long as those luminance conditions are not present in the visual field at the same time.[30] We considered it unnecessary to replicate those levels because glare sensation depends on the luminance the visual system is adapted to, therefore it is a relative concept. Conclusions of previous studies were used as a reference to set the lower level of *L* below 1.5×10^3 cd/m^2 and a luminance ratio between task and window below 1:100 and the higher level above 1.5×10^3 cd/m^2, with a luminance ratio above 1:100.[31,32] The levels of this factor are coded *L* for low and *H* for high luminance contrast. The mean window luminances, standard deviations and luminance ratios are given in Table 1.

Table 1 GSV results for the glare-insensitive group (GI) and the glare-sensitive group (GS) for each treatment. Glare Sensation vote ratings: JP: Just Perceptible; JA: Just Acceptable; JU: Just Uncomfortable; JI: Just Intolerable. L_s – source luminance, L_t – task luminance. Also shown are the calculated DGI, the mean luminances of the glare source and the task on the screen and the associated standard deviations (SD)

	Group	GSV		DGI	L_s (cd/m^2)	L_t (cd/m^2)	L_s/L_t ratio
		Median	Rating				
PLH	GI	3	JU	24.3	1.82x10^3	5.20x10°	3.50x10^2
	GS	**4**	**JI**				
ALH	GI	2	JA	20.1	SD:188.6	SD:0.83	
	GS	**3**	**JU**				
PSH	GI	1	JP	22.9	1.91x10^3	6.40x10°	2.99x10^2
	GS	**3**	**JU**				
ASH	GI	1	JP	16.4	SD:135.1	SD:0.89	
	GS	1	JP				
PLL	GI	1	JP	17.1	2.83x10^2	5.40x10°	5.25x10^1
	GS	**2**	**JA**				
ALL	GI	1	JP	17.6	SD:72.9	SD:0.89	
	GS	1	JP				
PSL	GI	1	JP	15.6	3.37x10^2	5.40x10°	6.24 x10^1
	GS	1	JP				
ASL	GI	1	JP	13.0	SD:23.8	SD:0.89	
	GS	1	JP				

The second factor was the source size. Other glare studies defined this factor as the window/wall area ratio.[18,29] However, we considered the apparent source size in steradians (sr) by means of the subtended solid angle of the source at the eye of the subject. The lower level was the typical minimum size of an actual window. Hopkinson said that this size is 0.01 sr.[15] The human visual field covers 2Πsr. As the subtended angle approaches this size the source begins to impact visual adaptation, lowering the chances of glare.[33] The higher level for the source size factor considered that phenomenon and was set at 0.66 sr. We coded this factor as *S* for small and *L* for large source sizes.

The third factor is viewing and is defined by the frequency with which the source occupies the central visual field. In actual work spaces the field of view is centred on the task and, depending on the equipment layout, the glare source is somewhere around the task within the workeŕs field of view. Eventually the worker may look directly at the window, but most of the time he is looking at the computer screen (and is adapted to its luminance). We defined two viewing conditions: In the prosaccadic condition (coded *P*) the participants had to shift their vision between the source and the computer screen, a visually demanding scenario in terms of visual adaptation. In the antisaccade condition (coded *A*), the subjects had to fixate on the computer screen, ignoring the glare source. We recorded every run with a webcam to verify the eye position of the subjects.

3.2. Glare sensation vote

The basic problems for the prediction of discomfort glare remain, because little is known about the physiological and psychological basis of the discomfort experienced.[24] Discomfort glare is essentially a subjective phenomenon and requires research methods that involve subjective judgments. The assessment method chosen was the semantic differential scaling using the glare sensation vote (GSV). This estimates the glare sensation as a function of the time the subject could stand the sensation of discomfort.[15] The criteria of this ordinal scale are: Unnoticeable Glare (UG), Just Perceptible (JP), Just Acceptable (JA); Just Uncomfortable (JU); Just Intolerable (JI). We arbitrarily assigned zero to UG and four to JI, in order to calculate medians. A digital form that included a definition for each point, presented the scale on the screen. For instance, Just Intolerable was defined as the situation where the subject could not stand the discomfort caused by the glare source and, if given the chance, would *immediately* take action in order to reach a state of comfort. This scale has been widely used since its introduction.[16,25,34] The borderline between comfort and discomfort (BCD) is somewhere between 'just acceptable' and 'just uncomfortable'.[19]

3.3. Glare analysis from high dynamic range images

We calculated the daylight glare index (DGI) from luminance maps created as high dynamic range images (HDRI).[35,36] A series of low dynamic range images (LDRI) were taken with a Nikon Coolpix 5400 camera with a Nikon FC-E9 fish eye lens. Each image was taken from the subjects' eye position, pointing to the centre of the VDT or the centre of the artificial window. The LDRIs were processed with Photosphere for MAC OS. As the information stored in the HDRI corresponds to photometric values of luminance, this technique replaces point measurements taken with a luminance meter.[37] However, we used a Minolta LS100 luminance meter to obtain control luminances in the higher and lower extremes of the dynamic range to calibrate the scenes. We processed the HDR images with Evalglare software and calculated DGI for each treatment.[18] The borderline between comfort and discomfort (BCD) corresponds to 22 on the scale.[38]

3.4. Reading span task

We developed a digital version of the reading span task (RST). This is a complex performance measure that correlates with a wide range of higher order cognitive tasks present in VDT work.[39,40] The subjects were required to read aloud at their own pace sentences presented on screen and to remember the last word of each sentence for later recall. To include processing as well as storage, the subjects also had to indicate whether any word of the sentence had a spelling error or not. The sentences were presented in groups that ranged in size from two to six. A subject's working memory span was the level at which he or she could correctly recall two of the three items. For example, if a subject were to successfully recall at least two out of three two-word items, the experiment would continue for the subject to attempt three-word items. If the subject were then successfully to recall only one out of three of the three-word items, the experiment would terminate, and the subject's working memory span would be two.

Each group of sentences appeared, one sentence at a time, in white text on black background (mean luminance contrast = 2.21), in a Verdana 12-point font (subtended angle on the eye = 0.00006 sr), left aligned and centred on the screen. Each sentence was visible for six seconds and then disappeared. In the prosaccadic condition, once the subject read each sentence, he or she was instructed to look for two seconds at the centre of the glare source. The subject then had to press the spacebar to read the next sentence. In case the subjects were still fixating at the glare source while pressing the spacebar, a delay of one second between the slides would allow them to have approximately the same time for reading in prosaccadic and antisaccadic treatments. At the end of each set of sentences a blue screen appeared, indicating to the volunteer that he had to say aloud the words he had in his memory. To move to the next set of sentences the subject had to press the spacebar. A total of 800 different sentences were generated with a length of 8 to 12 words each and were randomly presented to each subject. The last word of the sentence, which should be remembered, varied from one to four syllables. The task performances on each treatment and the effects of the experimental factors on working memory span are beyond the scope of this paper and have already been published by these authors.[41]

3.5. Experimental setting

The experiment took place inside the experimental light laboratory (Figure 1) at CCT CONICET-Mendoza, Argentina. Inside the 11.3 m^2 floor area and 2.7 m high experimental room we arranged a computer workstation. The walls and roof were painted black (wall reflectance = 0.048) in order to obtain a higher contrast between the glare source and its background. A black Compact Presario F700 notebook, TFT 14.2″ (screen apparent size = 0.342 sr; screen reflectance 0.036; keyboard reflectance 0.044) widescreen presented the RST task and the GSV digital form. The workstation geometry was the same for every subject thanks to chair adjustments and a chinrest to keep constant the geometry between eye, screen and light source (Figure 1).

The large area source was an artificial window 1.5 m wide and 1 m high (Figure 1). Two openings behind it improved ventilation and air exchange with the exterior. Inside the window, aluminum paper reflected the light generated by the multiple sources making the device more efficient. We randomly arranged 54 incandescent lamps in a 6×9 matrix. The power of the light sources varied between 40 W and 150 W. A plastic diffuser prevented direct vision of the lamps and a cardboard shutter allowed us to change the size of the source (from an apparent size of 0.667 sr to an apparent size of 0.017 sr). Both sources were centred on the subject's horizontal line of

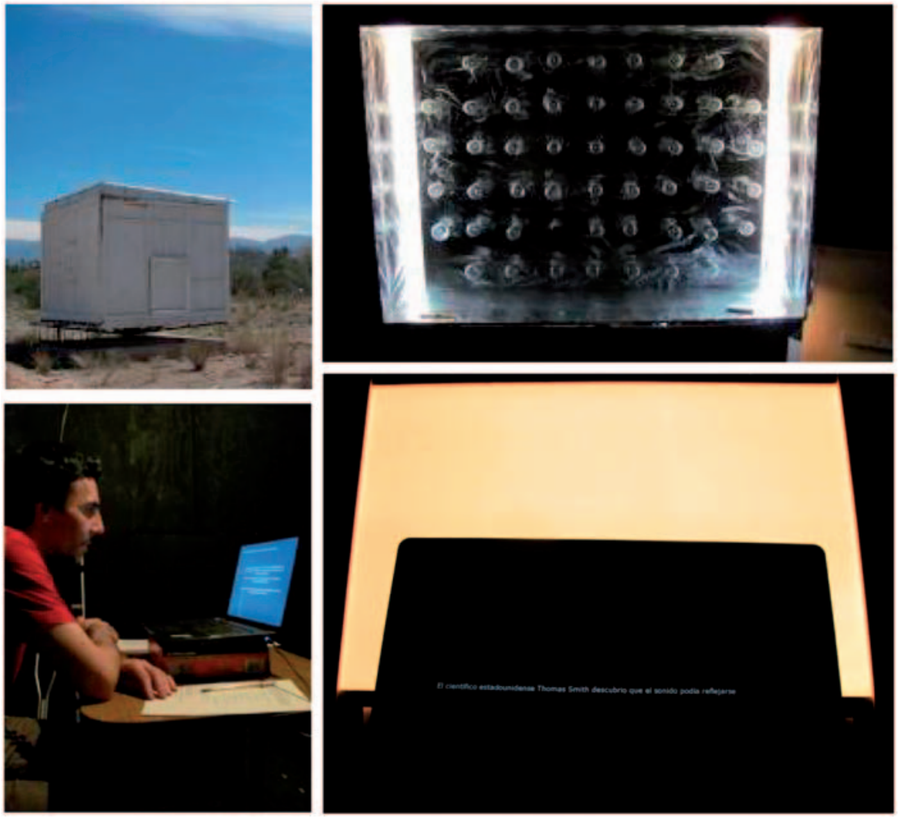

Figure 1 The setting of the experiment: (a) an outside view of the laboratory; (b) the artificial window without its diffusing screen showing the incandescent lamps; (c) the computer workstation geometry; (d) the RST in progress with the glare source turned on from the subject's viewpoint

vision so the angular shift between large and small source conditions was the same. The window was supported at 85 cm height by a metallic structure, immediately above the notebook screen.

3.6. Procedure

Data collection lasted 90 days, with morning sessions where each subject judged his glare sensation after performing the RST in eight randomly presented lighting treatments. A training session allowed the subjects to practice the RST and understand the GSV scale. In this pre-experimental session the volunteers also completed a general demographic survey (age, sex, eyeglasses usage, glare sensibility). Our 25 volunteers went through two experimental sessions in order to measure the GSV within-subjects variance. Each session was recorded with the notebook's web cam which allowed us to register the initial and the final time of the session. The volunteers passed through the eight treatments (T1 to T8) of the factorial design, which were randomised to avoid order effects. In each treatment, the subjects performed the RST and then they completed the GSV digital form for that treatment, while the experimenter prepared the next treatment. Once glare sensation had been assessed for a given treatment, the next one began and the

RST–GSV sequence was repeated under a different lighting environment. Before the fifth scenario there was a 10-minute break to minimise fatigue. The session was video recorded, initial and final time was registered, and room temperature was monitored ($27 \pm 3°C$) with a LMT 8000 multiple environmental measurement device during the session.

3.7. Subjects

The participation requirements were ages under 35 years, normal or corrected vision and not being under any medical treatment. Our sample of 25 volunteers was divided into two groups. The first group of subjects ($N = 9$; 36% of the sample) defined themselves as glare insensitive, had a mean age of 30.9 years (SD: 3.95) and divided into 33.3% males and 66.6% females. The second group ($N = 16$; 64% of the sample) consisted of self reported glare-sensitive persons, had a mean age of 28.6 years ($SD = 3.84$) with 31.3% males and 68.8% females. Our distribution of glare-sensitive and glare-insensitive subjects was similar to that found by Yun et al. They found 39% ($N = 20$) of glare-insensitive individuals and 61% ($N = 13$) of glare-sensitive volunteers.[27] In our study, women outnumbered men in both groups; however, no gender differences in glare sensation vote has been found in previous studies so no confounding effects were expected from this sample's gender distribution.[17] Both groups showed different eye glasses usage. About half of the glare-insensitive subjects (56.4%) wore eyeglasses while only 18.8% of glare-sensitive persons had corrected to normal vision. Scott-Linney tested the hypothesis that subjects who normally wear corrective lenses at VDT work would experience more severe visual discomfort than those who do not normally wear corrective lenses.[42] He reported some evidence in that direction but it was inconclusive. Our data shows an opposite trend, coincident with previous research.[7]

4. Results

We obtained luminance maps of the glare source by means of HDRI and then we processed them with Evalglare software. Finally we calculated DGI for each treatment. Table 1 shows the calculated values of DGI and the subjects' GSV medians for each treatment. Regarding the DGI results, it is not surprising that its value was higher when the size of the glare source was larger and when the luminance was higher. Setting the BCD at 22 points on the DGI scale, the equations predicted that the physical and photometric characteristics of the PLH and PSH treatments would cause discomfort glare for our subjects. However, this analytic method does not consider the different tolerances of people to glare, as can be seen in the higher medians in GSV reported by the glare-sensitive group compared to the non-sensitive group (highlighted in bold) for the same DGI score.

4.1. Individual and group differences in GSV

As we repeated our measurements in two different experimental sessions we were able to calculate the within-subject variance by means of the Wilcoxon test. The null hypothesis is rejected if p-values are below 0.05. Our results showed that except for the PLL treatment ($Z = -2.138$, $p = 0.033$), there was no within-subject variance in glare sensation between the two measurement sessions. Therefore, results related to PLL treatment should be handled with care.

Table 1 shows that glare-sensitive group and glare-insensitive group GSV medians were different for some treatments. Considering the ordinal nature of our dependant variable we tested if one of our samples of independent observations tended

Table 2 Mann–Whitney's *U* test comparing GSV ratings from glare-sensitives and glare-insensitives

	PLL	PLH	PSL	PSH	ALS	ALH	ASL	ASH
U Mann–Whitney	112.50	163.00	187.00	145.50	278.50	200.00	229.00	277.00
W Wilcoxon	283.50	334.00	358.00	316.50	806.50	371.00	400.00	448.00
Z	−3.749	−2.733	−2.181	−2.974	−0.205	−1.852	−1.281	−0.233
p-value	**0.000**	**0.006**	**0.029**	**0.003**	0.837	0.064	0.200	0.816

Table 3 Main and interaction effects of the source luminance, size and viewing conditions on glare sensation

	Glare-insensitives				Glare-sensitives			
	Effect	Coef.	*T*	*p*-value	Effect	Coef.	*T*	*p*-value
Position (P)	0.069	0.035	0.44	0.659	−0.578	−0.289	−4.45	<**0.001**
Size (S)	0.736	0.368	4.68	<**0.001**	0.641	0.320	4.93	<**0.001**
Luminance (L)	0.958	0.479	6.09	<**0.001**	1.063	0.531	8.18	<**0.001**
P*S	0.042	0.021	0.26	0.791	0.031	0.016	0.24	0.810
P*L	−0.014	−0.007	−0.09	0.930	0.047	0.023	0.36	0.718
S*L	0.542	0.271	3.44	**0.001**	0.516	0.258	3.97	<**0.001**
P*S*L	−0.208	−0.104	−1.32	0.187	0.188	0.094	1.44	0.150

to have larger values of GSV by performing a Mann–Whitney *U* test (Table 2).

For PLS, PLH, PSL and PSH treatments the independent categorical variable presented a *p*-value below 0.05, meaning that the subjects from the glare-insensitive group consistently reported a lower sensation of glare than volunteers from the glare-sensitive group with a confidence level of 95%. For ALS, ALH, ASL and ASH treatments there were no significant differences between glare ratings; glare-sensitives did not report different sensations than glare-insensitives. The ALH treatment, was considered glaring for sensitive persons but not glaring by non-sensitive volunteers, a difference that almost reached statistical significance ($Z = -1.852$; $p = 0.064$). Our results are consistent with Osterhaus,[24] who found that workers who indicated that they were sensitive to glare generally reported experiencing higher levels of glare.

4.2. Effects of experimental factors on GSV

Table 3 shows main and interaction effects of the experimental factors on glare sensation for the glare-insensitive and the glare-sensitive groups. The luminance and size of the glare source have similar main and interaction effects on both groups. However, shifting fixation between the source and the task has different effects on the two groups: For the non-sensitive group there was no change in glare sensation for prosaccadic and antisaccadic viewing but for the sensitive group higher glare sensations were caused by prosaccadic viewing than by antisaccadic viewing. This analysis of the observed effects suggests that it is only when occasionally looking directly at the glare source, that the glare-sensitive people experienced more glare than those who were not glare sensitive. This finding improves our understanding of discomfort glare since different glare sensations were not caused by the two most important factors linked to the glare phenomena, the source size and its luminance. Instead, differences arose from a task-related, behavioural factor; shifting or not shifting fixation between the VDT and the lighting source. Besides the interaction effect found between source size and its luminance, no other interaction effects were found.

Table 4 Ordinal regression to test the statistical significance of the observed effects

		Estimation	Wald	DF	Sig.	95% Confidence Interval	
						Lower limit	Upper limit
GS	Size	−1.183	20.052	1	0.000	−1.700	−0.665
	Luminance	−1.599	34.995	1	0.000	−2.129	−1.069
	Condition	1.069	16.603	1	0.000	0.555	1.584
GI	Size	−1.704	20.874	1	0.000	−2.435	−0.973
	Luminance	−1.493	16.014	1	0.000	−2.225	−0.762
	Condition	0.241	0.486	1	**0.486**	−0.437	0.919

In order to verify the statistical significance of these results we performed an ordinal regression for both the sensitive and insensitive groups (Table 4). The ordinal regression analysis output showed the statistical significance of the effects caused by the size and luminance of the source with *p*-values below 0.0001. It also confirmed that shifting fixation between source and task had statistically significant effects on glare sensation in sensitive persons ($p<0.0001$) but not in non-sensitive people ($p<0.486$).

A standard statistical manoeuvre for testing whether a model fits is to compare observed and expected values by means of Pearson goodness-of-fit measures. If the model fits well, the observed and expected cell counts are similar, the value of each statistic is small, and the observed significance level is large. The null hypothesis that the model fits is rejected if the observed significance level for the goodness of fit statistics is small. Good models have large observed significance levels. Pearson goodness of fit measures for the glare-insensitive subjects had a *p*-value of 0.760 ($DF=21$; $\chi^2=16.168$) and for the glare-sensitive volunteers had a *p*-value of 0.169 ($DF=21$; $\chi^2=27.052$). The large observed significance levels indicate that the observed data are consistent with the fitted model, showing its capacity as a predictor.

5. Discussion

In this study, we classified our subjects in relation to their self-perceived tolerance to glare, obtaining two groups; those glare-sensitive and those glare-insensitive. We found that the former group consistently reported a higher sensation of glare in the presence of a glare source in central vision (prosaccadic treatments) than the latter group. Given this, what are the probabilities of being disturbed by a glare source for that group? We measured the degree of discomfort by means of the Glare Sensation Vote, which is an ordinal scale with a threshold (the borderline between comfort and discomfort) set between ‘just acceptable’ and ‘just disturbing’. We transformed our ordinal scale into a dichotomous variable in order to calculate the relative risk of being disturbed by the glare source. We recoded the first three steps of GSV as ‘No sensation of discomfort glare’ and the final two steps as ‘presence of sensation of discomfort glare’. Table 5 shows the frequencies of occurrence of the event ‘discomfort glare’ for both groups in our eight treatments. The relative risk (RR) associated is also presented with a confidence level of 95%. When the risk is equal to one, the probability of being disturbed is the same for both groups. If the confidence interval contains the number one, then the RR is not

Table 5 The risk that the glare sensitive will experience discomfort glare relative to the glare insensitive for the eight treatments

	DGI	Group	Glare		Relative risk	95% Confidence interval	
			NO	YES		Lower	Upper
PLL	17.1	GI	16	2			
		GS	8	24	**6.75**	**1.800**	**25.315**
PLH	24.3	GI	1	17	1.06	0.947	1.184
		GS	0	32			
PSL	15.6	GI	16	2			
		GS	18	14	**3.94**	**1.006**	**15.409**
PSH	22.9	GI	13	5			
		GS	8	24	**2.70**	**1.249**	**5.839**
ALL	17.6	GI	12	6	1.03	0.459	2.318
		GS	21	11			
ALH	20.1	GI	4	14	1.21	0.927	1.567
		GS	2	30			
ASL	13.0	GI	15	3	1.69	0.523	5.449
		GS	23	9			
ASH	16.4	GI	11	7	1.13	0.559	2.265
		GS	18	14			

statistically different to one. Statistically significant risks are highlighted in bold.

Considering the experimental correlation between GSV and DGI[38]: 16 = Just Perceptible, 20 = Just Acceptable, 22 = BCD, 24 = Just disturbing, 28 = Just intolerable, the DGI equation failed to predict the differences between glare-sensitive and glare-insensitive persons. Similar DGI scores on PLL (DGI = 17.1) and ALL (DGI = 17.6) treatments did not describe the actual differences in glare sensation of both groups, best described by the higher relative risk of being disturbed we found in glare-sensitive subjects for the PLL treatments (RR = 6.75), when the glare source briefly occupied central vision while performing the VDT task. Table 1 shows that for the PSL treatment (DGI = 15.6) both sensitive and insensitive people had the same median; however, relative risk analysis showed that glare-sensitive subjects had almost four times more chance of experiencing discomfort. For both lower and higher scores of predicted glare sensation by means of DGI, no differences were found in terms of relative risk between glare-sensitive and glare-insensitive groups. However, when the equations predicted glare sensations near the BCD for mild degrees of predicted glare (DGI = 24) and when the source occupied the central part of the visual field, glare-sensitive persons did not have a greater probability of being disturbed by the glare source. In PSH treatments (DGI = 22.9), glare-insensitive individuals mostly rated the glare source as just acceptable (Table 1) but glare-sensitive subjects considered it as just disturbing, a sensation above the borderline between comfort and discomfort. The relative risk of being disturbed near the BCD was 2.70. None of the antisaccadic treatments showed different probabilities of being disturbed between glare-sensitive and glare-insensitive samples.

The statistical analysis of the observed effects proved that it is only when occasionally looking directly at the glare source, i.e. in the prosaccadic condition, that the glare-sensitive people experienced more glare than those who were not glare sensitive. A well-known ergonomic criterion states that considering the least suited subjects for a situation allows not only fitting those individuals, but most of the rest of the population as well. Considering that some people are less tolerant of glare, then defining a borderline between comfort and discomfort based on glare-sensitive individuals will avoid disturbance regardless of individual differences in glare tolerance and result in a glare-free, inclusive visual environment.

The limited study of discomfort glare tolerance for a large area source and VDT work presented here is based on a subjective appraisal. Some concerns might rise from this methodological choice but discomfort glare is a common sensation and we believe that people can properly define themselves as sensitive or insensitive in terms of glare in the same way we all know if we are prone to feel cold or not. It is a more direct approach compared to behavioural proxies such as sunglass usage and it is non-intrusive in relation to proposed objective glare measurement methods (e.g. correlating the electrical activity associated with facial muscles and its relation to discomfort glare).[43]

Our conclusions are limited to relatively young visual systems. Persons over 50 years old could tolerate only half the glare acceptable for 25 years olds.[44] As older people are more sensitive to glare, it is possible that in a randomly selected sample of persons with an aged visual system, the proportion of self-defined glare-sensitive persons would be higher and their differences might be wider. There are also cultural differences that affect glare perception. Research has shown that Japanese subjects are more tolerant of discomfort glare, narrowing the scope of our results.[45] This experiment was carried out in a single location with subjects habituated to a specific climate, sky condition and luminous environment. Habituation is a physiological storage response to external stimuli that reduces the response to unwanted or irrelevant stimuli, such as a glare source.[46] Further climate based, comparative research is required to describe glare sensitivity as a function of the local luminous environment people are habituated to.

6. Conclusions

Discomfort glare is a major issue for lighting and daylighting design. A large body of knowledge has been developed around the assessment of visual comfort, associated to the absence of discomfort glare indoors from both electric and natural light sources. However, the basic problems for glare prediction remain.[47] Discomfort glare is a sensation, and must be assessed as a subjective response. However, engineers have developed formulae to quantify it and we have agreement on the factors that cause glare and the basic trends. The analytic methods available do not consider, among other issues, the different tolerance of people to glare as can be seen in the large variation of responses normally found when comparing individual subjects. In order to describe and understand the differences in glare sensation between glare-sensitive and glare-insensitive subjects we designed an experiment where discomfort glare from an electric light source was assessed while performing a VDT task.

We found similar statistically significant effects of luminance and size on glare sensation for both groups. However, when occasionally looking directly at the glare source, glare-sensitive people experienced more glare than those who were not glare sensitive. In these scenarios, glare-sensitive people had a higher relative risk of being disturbed. This finding improves our understanding of discomfort glare, since different glare sensations were not caused by the two most important factors linked to the glare phenomena but by a task-related, behavioural factor; shifting or not fixation between the VDT and the lighting source. After a century of research, it is time to widen the reductionist search for basic physiological mechanisms of glare.

Disturbing glare is an unwanted outcome of the complex dynamic of people performing a task in a certain environment and it can only be fully understood and prevented – if viewed as a whole. Considering our data we propose the concept of an 'inclusive visual environment'. By defining a borderline between comfort and discomfort based on glare-sensitive individuals' response, disturbance for both sensitive and insensitive people will be avoided.

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