Surprising results from a Post Occupancy Evaluation of the way internal roller blinds impact perceptions of visual discomfort.

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Abstract
Blinds and shutters are one of the few products in the built environment that affect perceptions of visual and thermal comfort. However, in general, internal roller blinds are more frequently installed in UK offices to improve visual comfort as opposed to thermal comfort. With the increased frequency in warmer weather events resulting from climate change it is likely that blinds will be extended more frequently to improve thermal comfort as well as reducing perceptions of glare and visual strain. When internal shading products are extended it is assumed that glare and visual strain will no longer be experienced. However, when conducting a Post Occupancy Evaluation (POE) into whether the position of roller blinds (either fully extended or fully open) affected perceptions of glare, a greater level of visual discomfort (specifically glare) was experienced by occupants when shading products were closed. Distributions of light around the task area play an important role in improving visual comfort when occupants are carrying out desk-based activities yet moveable shading is frequently excluded from daylight simulation assessments of visual comfort. The closure of blinds can affect the distribution of daylight within a space and thus occupants can perceive glare issues from other internal sources of light. This research suggests that the deployment of shading products should be considered in the assessment and predictions of internal lighting conditions to provide lighting designers with a more holistic view of visual comfort throughout the year. Furthermore, in POE it would be beneficial to ask occupants what they believe the glare source to be.

Keywords Shading, Roller Blinds, Glare, POE, Visual Comfort

1.0 Introduction

The research described in this paper reports the results of a POE evaluation conducted on occupants within two offices where blinds were either extended or retracted. Statistical techniques were used to make comparisons between occupant responses to determine whether the shading products installed were effective at preventing glare issues and reducing experiences of visual strain when extended. Supplementary mean hourly lux level data was also collected to support the questionnaire data collected.

Prior to conducting the study, the research team hypothesised that the results of the POE related to glare experiences and visual strain would show that when the internal blinds were extended, occupants would report less glare experiences and visual strain. However, the results showed that participants had more frequent experiences of glare when the blinds were extended, and the level of visual strain experienced did not differ between the two conditions. This paper tries to explain the reasons for these unexpected results and highlights why internal shading products should be considered within POE assessments and lighting design evaluations.

The study described in this paper is part of a larger study which investigated how the position of internal blinds affected occupants' health, well-being, comfort, and productivity as part of a PhD Research project conducted at London South Bank University and in collaboration with the British Blind and Shutter Association. In this paper only the aspects related to a selection of the visual comfort questions asked and the monitoring of the lighting conditions are described and analysed. Further details of the larger study can be found within De Grussa (1) and De Grussa *et al* (2).

2.0 Background

Lighting designers are tasked with reducing the risk of discomfort glare from interior electrical lighting and daylight. The recently introduced Daylight Glare Probability (DGP) metric considers both glare caused by artificial and electric sources (3). However, many buildings change use, or an offices furniture layout may change over the duration of a buildings' lifetime, but detailed evaluations of how these changes affect occupants' visual comfort are rarely carried out. One of the main ways in which glare issues are identified is through occupant complaints to facilities' managers. Post Occupancy Evaluations (POE) offer a way in which facilities' managers can systematically check whether changes made to the office environment positively or negatively affect occupants when occupied (4).

When glare issues arise in offices they are often related to the penetration of high levels of daylight. The Health & Safety (Display Screen Equipment) Regulations 1992 (as amended by the Health and Safety (Miscellaneous Amendments) Regulations 2002 (5) state:

"Workstations shall be so designed that sources of light, such as windows and other openings, transparent or translucid walls, and brightly coloured fixtures or walls cause no direct glare and no distracting reflections on the screen. Windows shall be fitted with a suitable system of adjustable covering to attenuate the daylight that falls on the workstation."

Therefore, internal shading products are viewed as one of the main means of controlling glare caused by high levels of daylight. If glare issues are then reported when internal shading products are available to occupants, they often perceive the shading product as inadequate at preventing glare.

The closure of shading products also alters the distribution of light around the visual task area as they can reduce the peripheral illuminance levels significantly.

Within the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) guidebook No 12: Solar Shading (6) it is suggested that luminance ratios, measured in Cd/m^2, of 1:3:10 should be targeted for good visual comfort when the main light source is daylight and the reverse (10:3:1) should be sought when artificial light is the main light source. When applied this ratio suggests that the central field of view should be no more than 3 times the luminance of the visual task, and no less than one third of it. Additionally, the peripheral field of view should be either 1/10th or 10 times the luminance level of the visual task. The application of this ratio is illustrated in Figure 1.

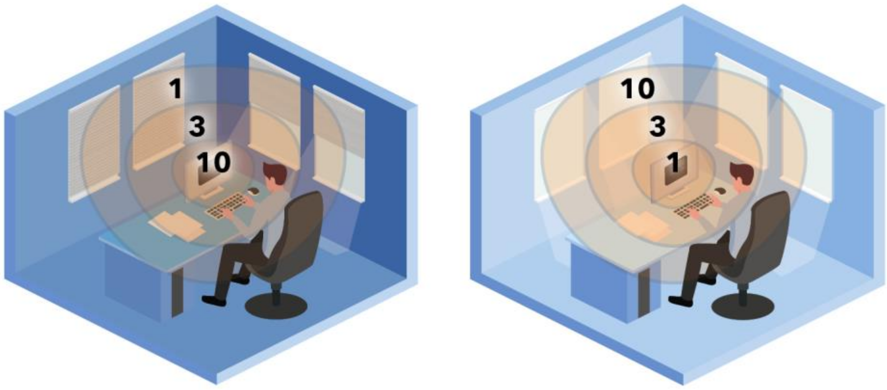

Figure 1. Luminance ratios for good visual comfort. (Left) In the case of artificial light and (Right) in the case of daylight.

Even though the extension of shading products can significantly alter the distribution of light within a space, they are often only considered and specified within the furnishing stage of a building and the ramifications of closing shading products in conjunction with the use of lighting systems is not commonly assessed or evaluated within POEs.

Whilst all shading products are rarely permanently closed within an office during the day, in some naturally ventilated offices it may become more common for shading products to be extended to prevent incoming solar gain causing thermal discomfort due to climate change. Shading is highlighted as one of the main ways in which increasing internal temperatures can be mitigated, and although external shading is more effective in preventing incoming solar gain, in many building types internal shading may be the only feasible option (7,8). For example, within heritage buildings, the retrofit of high-rise buildings where moveable shading is prohibited by high wind velocities, and where external shading cannot be easily retrofitted due to architectural constraints.

2.0 Methodology

2.1 Case Study Building

The study was conducted in four open-plan office spaces, situated on the second floor of the two-storey building in London South Bank University's (LSBU), Clarence Centre building. Each office had two south-west facing windows (230.02º) - which can be observed in the top image of Figure 2. - and one north-east facing window and a rooflight. The north-east facing window looked out onto an open courtyard area which had minimal planting. The four offices were of almost equal size with an average floor plate of 39.19m^2 and had similar sized glazed areas with an average wall to window ratio of 12:1.

Figure 2. (Above) South-west façade of offices tested. (Below) Internal office layout of Office B (both images taken with a fisheye lens).

The four open-plan office spaces were divided into two groups Office A and Office B observed in Figure 3. Each of the rooms could be occupied by 14 to 16 occupants at one time but full capacity was rarely reached as hot-desking and the use of meeting rooms frequently occurred.

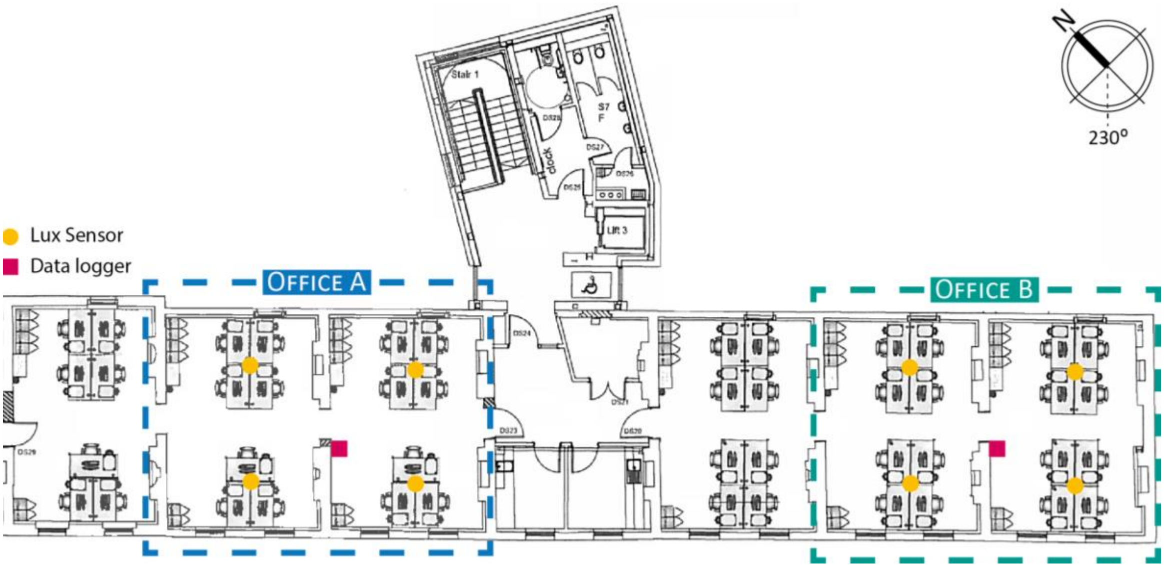

Figure 3. Plan view of assigned Office A and B and sensor layout.

The offices were furnished and finished in a similar way – the walls were painted matte white, the floors were carpeted with dark grey carpet and both offices were laid out with desks, chairs, and metal/wooden cabinets – however, there were some differences. In Office A the desks had a wood finish with light green partitions whereas in Office B the desks had a white finish and had no partitions. To ensure each group of occupants was exposed to similar illuminance conditions partitions were added to Office B two weeks prior to the start of the study.

The roller blind dim-out fabric (with an unknown visual solar transmittance value) installed on the vertical facades were also replaced by a screen fabric with known values according to BS EN 14501:2021 (9). The fabric had a visible light transmission, τ_v, of 0.8, with an openness coefficient of 4%.

BS EN 14501: 2021 provides a method for classifying shading performance on a 0 - 4 scale with 0 representing 'very little effect', and 4 representing a 'very good effect' the shading fabric chosen had a Class 1 - 'little effect' - for glare control.

Figure 4 shows the view out of one of the south-west windows in Office A with the newly installed blind extended and retracted. This shows that some provision of a view out was still possible when the blind was extended. This view out represents a Class 3 – 'good effect' – for 'Contact with the outside' according to BS EN 14501 (9). BS EN 14501 also classes shading performance for their daylight utilisation, room darkening, night privacy, rendering of colours and ability to control solar gains amongst other thermal performance factors.

Figure 4. Window views with blind extended (Left) and with blind retracted questions (Right) out of south-west windows in Office A.

The shading products installed on the rooflights were not replaced. This consisted of a Velux system with an opaque blind fabric that was controlled via a manually operated motorised switch fixed to the north-east façade wall. The artificial lighting system was provided by tube lighting (35W/840) which linked to an occupancy sensor.

This study was conducted prior to the publication of BS EN 17037 – Daylight in Buildings (3) and the revised BS EN 14501 which both provide recommendations for the specification of shading products to avoid glare based on the Daylight Glare Probability (DGP) metric. The DGP values are categorised according to Table 1.

Criterion	**Daylight Glare Probability (DGP)**
Glare is mostly not-perceived	$DGP \leq 0{,}35$
Glare is perceived but mostly not disturbing	$0{,}35 < DGP \leq 0{,}40$
Glare is perceived and often disturbing	$0{,}4 < DGP \leq 0{,}45$
Glare is perceived and mostly intolerable	$DGP \geq 0{,}45$

Table 1 – Daylight Glare Probability Categories according to BS EN 17037: 2018

In both BS EN 17037 and BS EN 14501 tables are provided to help designers select the appropriate class of glare control when taking into consideration various factors related to the design and location of the building, the position of occupants in relation to the window, and the desired DGP target.

In reflection of these tables the screen fabric selected – with a Glare Class of 1 – was insufficient to meet the DGP ≤ 0,35 criteria the tables in the standards depict that a Glare Class of 4 is more appropriate for both the SW and NE facing facades. However, a glare class of this performance would also result in a lower 'Visual contact with the outside' class.

2.2 Study Design

Nineteen participants (8 Male and 11 Female) participated in the study, and they all regularly worked in one of the two offices. They were informed that they would be asked to complete a series of relating to their work environment and take part in certain tests related to their work skills and cognitive ability. The work tests were part of the larger study previously mentioned and are not discussed within this paper. The participants were also informed that their office environments would be monitored, and interventions would be placed on the two office environments. They were asked not to interfere with the window and blind positions or the lighting, cooling, and heating equipment on test days. Participants were tested between 12pm and 1pm on Tuesdays and Thursdays over a two-month period between July and August in 2016.

Interventions were placed on the offices the day previous once the staff had vacated at the end of the day. The position of the blinds was the only variable that differed between the two offices, this alternated between being fully opened and fully closed across the 15 test days. The façade blinds were all manually operable with a chain and the roof blinds were motorised and could be extended or retracted using a wall switch. The first of the 15 test days was used to pilot the workings of the online questionnaire and the collection of environmental data. Unfortunately, not all participants could participate in every test session due to work commitments so the number of participants (N) in open and closed blind conditions on any one test day did vary. Additionally, on test day 14 one of the dataloggers failed to collect environmental data due to a connection issue. The data collected resulted in 74 complete sets (questionnaire and environmental data) of data for blind closed conditions and 97 sets of data for open blind conditions. However, a further 6 sets of questionnaire data were collected in the open blind conditions which have been included when evaluating questionnaire data alone.

2.2 Data Collection

2.2.1 Question Data

Participants were asked to respond to 17 questions regarding the internal environment conditions in total however this paper only analyses participants' responses to 4 of the questions as these are related to visual comfort. The questions presented to participants were replicated from research literature and had been previously recognised as ways of assessing visual comfort. The questions examined in this paper are listed in Table 2. Table 2 also displays the measure, the question format and either the response extremes that were presented on a Likert scale or the response categories displayed when the question was presented as a check-box question. Questions 3 and 4 were only presented to participants if they responded ‘Yes’ or ‘Sometimes’ to question 2 which asked participants whether they were experiencing any glare issues whilst they were sitting at their desk.

Q No.	Measure	Question Format	Response Extremes / Categories	
1	Lighting Sensation	How do you find the level of brightness within the room at present?	Very Dark (-3)	Very Bright (+3)
2	Visual Strain	Are you experiencing any strain with your eyes whilst completing the questionnaire?	No Strain (0)	Large Amount of Strain (2)
3	Identifiable Glare Issues	Are you experiencing any issues with glare from the computer or on your person whilst sitting at your desk?	Yes / Sometimes / No	
4	Glare Source	Can you identify the source of the glare?	Computer Screen / Window / Direct Sunlight / Internal Electric Lighting / Reflections of Sunlight / Unable to Identify	

Table 2 – Visual Comfort Questions

2.2.1 Environment Measurements

A broad range of internal and external measurements were monitored to establish the internal environments conditions as part of the broader study to determine how internal shading products affected occupants’ comfort, health, well-being, and productivity. However, in this paper only the internal horizontal illuminance, measured in lux, was evaluated. These data were collected using two automatic data loggers, one located in each office, that collected measurements every 10 minutes. The measurements were then averaged into an hourly average illuminance level for each participant over the duration of time that they answered the questions. Four lux sensors were also connected to each data logger and distributed throughout each office. The two dataloggers and lux sensors were calibrated prior to testing. The lux sensors used were a EKO-ML-020S-O (10) and these were connected to a dataTakerD500 and DT80 loggers. These specific lux sensors had a response curve that closely matched the CIE Photopic curve.

Lux sensors were placed at approximate head height (1.2m) and positioned on top of the partitions that were positioned between the participants’ desk locations. A plan view of the lux sensor locations is presented in Figure 3 which also shows the layout of the desks.

3.0 Results and Discussion

3.1 Blind Open vs Closed Internal Illuminance Levels

The mean hourly illuminance level over the duration of time that it took each participant to complete the various tests and questionnaires given was included within a box and whisker plot (Figure 5) to provide an overview of the lux levels experienced in blind open (N = 74) and closed conditions (N = 97).

The box and whisker plot identifies the overall mean (Δ) lux level measured across the test days, the median lux level measured (central line), the 25th percentile (lower line of the box) and the 75th percentile (upper line of the box), and the minimum (bottom whisker) and maximum data point collected (top whisker) when blinds were either open (orange box plot) or closed (blue box plot).

Several outliers were found when assessing the closed blind data, on the box plot these have been highlighted by a 'o' symbol. Conventionally outliers are viewed as datapoints that lie an abnormal distance from the other datapoints in the dataset. A datapoint is considered abnormal when it is below the 25th percentile or above the 75th percentile by 1.5 times the IQR. This was also the method used to determine the anomalies shown in Figure 5.

The box area of each box and whisker plot (i.e., the range in values between the 25th and 75th percentile) represents 50% of the illuminance levels measured when excluding the outliers. The whiskers (top and bottom) represent the top 25% and the lower 25% of illuminance levels measured. Therefore, it is observed that in open blind conditions the illuminance levels experienced were almost consistently above the comfort threshold (i.e., > 500 lux) whereas in the closed blind conditions approximately 75% of the mean hourly illuminance levels were below the minimum comfort threshold (i.e., < 300 lux) (11).

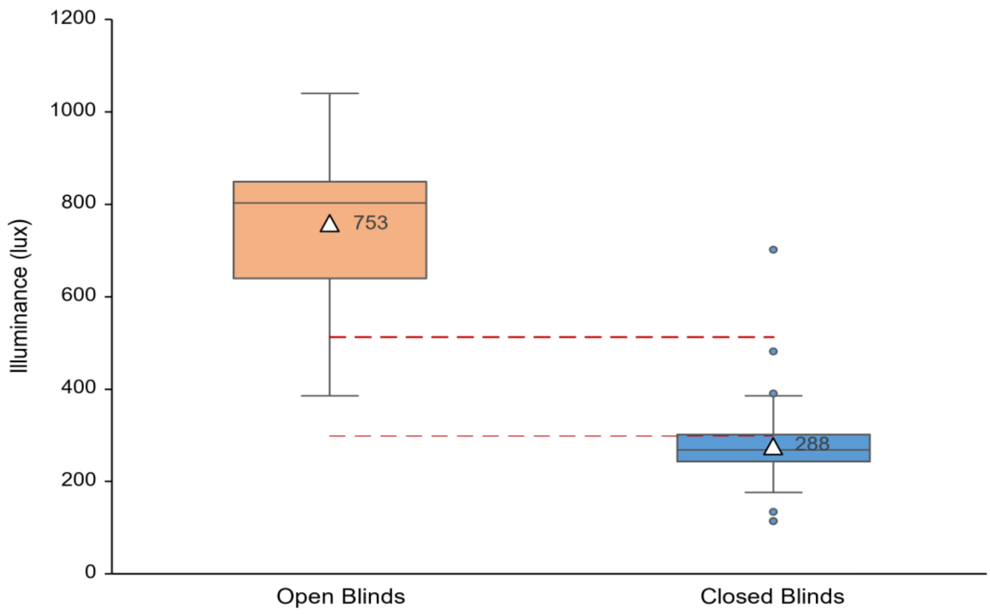

Figure 5. Test session mean internal illuminance between the open (N = 74) and closed blind (N = 97) conditions for each participant (dashed line = 300 - 500 lux comfort threshold, Δ = Mean).

3.2 Blind Open vs Closed Questionnaire Data

A Chi-square (χ^2) test was used to identify differences in the distribution of the responses provided by the participants in either open or closed conditions. This method of analysis was only considered to be appropriate as the overall external environment conditions were not notably different when each group of participants responded to the tests and questionnaires in either the open or closed blind conditions.

The output of the Chi-square is a χ^2 statistic and an associated significance level. The χ^2 statistic tells us how much of a difference exists between the data collected and what we would expect to see if there was no relationship. A significant result (by convention, usually taken as $p < 0.05$) indicates that the result did not occur by chance and that the position of the blinds altered the outcome. This statistical technique is only appropriate in the assessment of categorical data. In total, 177 questionnaire responses were evaluated which were split into two groups: participants in the closed blind conditions (N = 97) and participants in the open blind conditions (N = 80).

Overall, three of the four measures of visual comfort had significantly different distributions of responses between the open and closed blind conditions. Considering that extending shading products attenuates incoming daylight and helps to reduce the risks of glare exposure, it was unsurprising to find significant differences between the two groups. Participants' perception of the brightness, χ^2 (7, N = 177) = 98.98, $p < .001$, participants experience of glare issues, χ^2 (3, N = 177) = 33.34, $p = .02$ and the source of the glare, χ^2 (3, N = 177) = 33.34, $p = .02$, were all significantly different between blind open and blind closed conditions. Figures 6 – 8 show the distribution of the responses provided between blind open and closed conditions for these significant results.

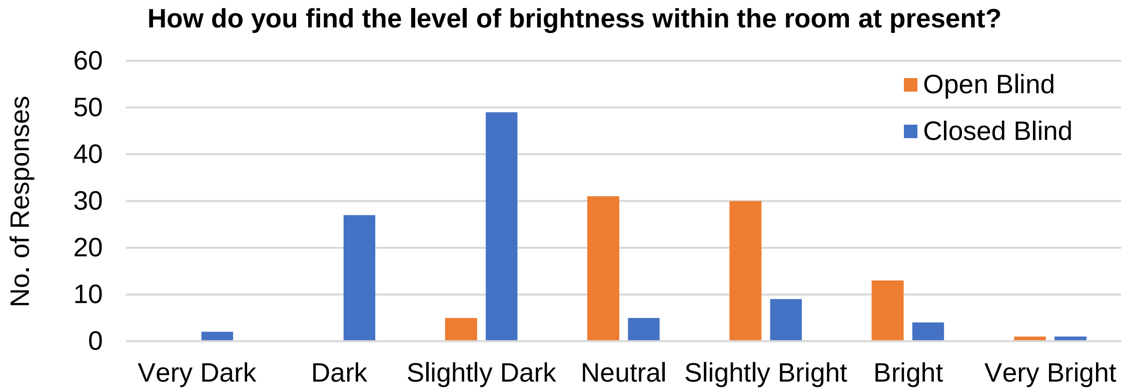

Figure 6. Lighting Sensation between the open (N = 80) and closed blind (N = 97) conditions.

The distribution of responses to the light sensation question (Figure 6) shows that the participants in the open blind conditions found the conditions to be brighter. However, it was surprising that fourteen participants identified that the conditions were either 'Slightly Bright', 'Bright' or 'Very Bright' when the blinds were closed. Generally, when blinds are closed, the conditions are perceived as darker because they reduce the amount of incoming daylight and subsequently the internal illuminance level. These results have been further explored in Section 3.3.1, which compares the participants' lighting sensation responses with the measured internal illuminance level.

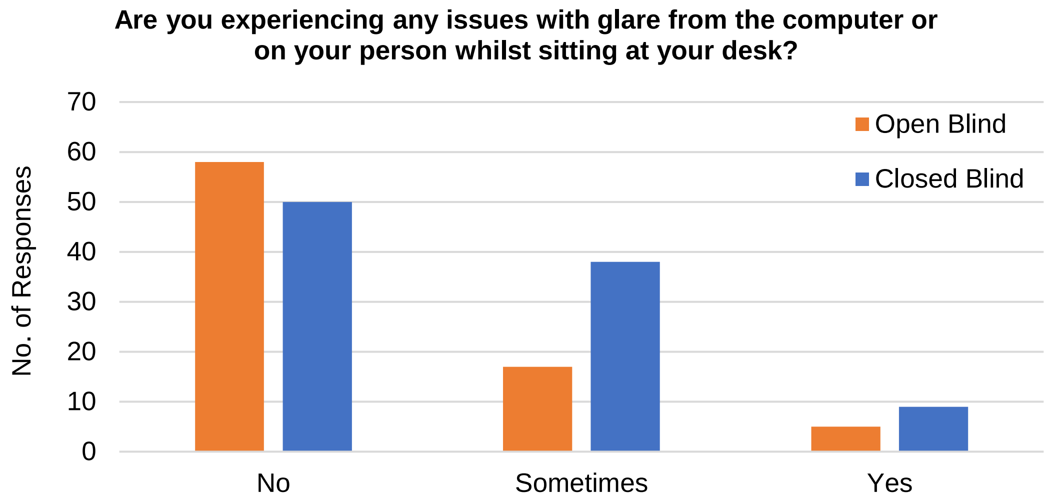

Figure 7. Identifiable Glare Issues between the open (N = 80) and closed blind (N = 97) conditions.

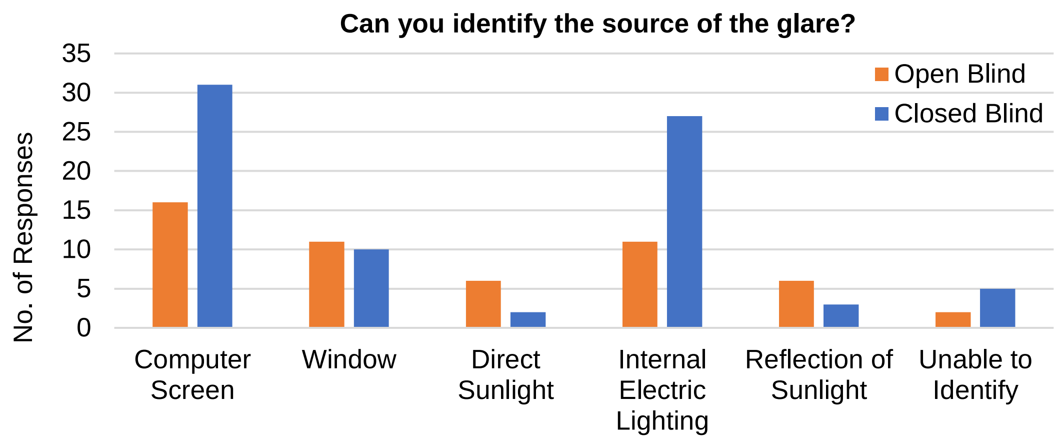

Figure 8. Glare Source between the open (N = 52) and closed blind (N = 78) conditions.

Figures 7 and 8 show that the participants in closed blind conditions experienced more glare issues and that these issues were most frequently related to the 'computer screen' or the 'internal electric lighting'. This was an unexpected result as generally glare issues are considered to occur more frequently when the blinds are retracted and when the illuminance levels are high. However, they can also be perceived when there is an uneven distribution in illuminance around the visual task. We can speculate that closing the blinds in the offices reduced the peripheral illuminance, and the light emitted from artificial lights (overhead lights and computer screens) may have created too harsh a contrast between the visual task, the central field, and the peripheral area of the room. This can contribute to visual discomfort and glare issues (6).

Figure 8 also shows that a small number of participants attributed the glare issues they experienced when the blinds were closed to being caused by 'Direct sunlight' (N = 2) and 'Reflections of sunlight' (N = 3). Considering the shading fabric glare class was not optimal for glare control it is unsurprising that some instances of glare were experienced.

Only participants that responded 'Yes' or 'Sometimes' to the glare question were asked their opinion on the magnitude of the glare and how it made them feel. There was no significant difference between the distribution of responses between the participants in open and closed blind conditions to the visual strain question posed ($p = 0.2$). This suggests that the magnitude of visual strain experienced and reported by participants was relatively similar in both conditions. Figure 9 shows the distribution of responses for the visual strain measure.

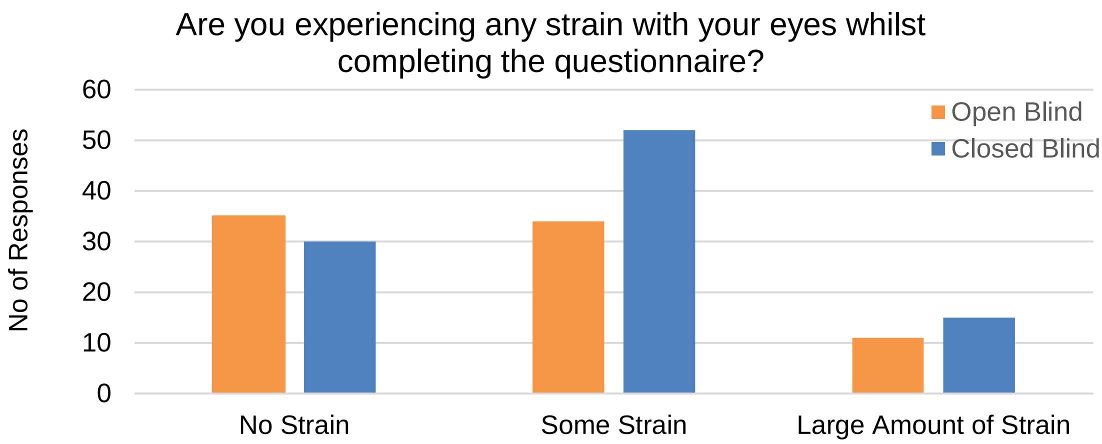

Figure 9. Visual Strain between the open (N = 80) and closed blind (N = 97) conditions.

In reflection of the study design, it is likely that if the shading products were able to be operated freely by the participants, we would observe significantly different results. The most significant driver for motivating internal blind use is related to visual comfort (12). Therefore, it is likely that if the conditions were free running that when occupants experienced glare from the artificial lighting when the blinds were closed that occupants would have either dimmed the artificial lighting or opened the blinds to improve the distribution of light. In practice when automated shading systems are included it is strongly recommended that manual overrides (i.e., wall switches) are included within the system so any unwanted blind movements can be rectified by occupants (12,13).

3.3 Cross Analysis of Internal Environment Data and Questionnaire Data

Spearman’s Rho correlation was used to identify the relationships between the mean hourly internal illuminance measured in relation to each participant during each test session and the responses participants gave to the questions. Correlations were also performed on the subsects of data from participants in open and closed blind conditions.

A Spearman’s Rho correlation is statistical technique which identifies what relationships there are between two variables and it informs us of their strength (strong or weak), including whether they are positively or negatively correlated and the significance of these relationships. A strong relationship is identified if the $r_s \geq 0.8$. The strongest relationship possible is a relationship of 1 which would mean that as one variable increases by one, the other variable would also always increase by one. A weak relationship is found when the $r_s \leq 0.3$. The polarity of the integer of the r_s defines the direction (positive or negative) of the relationship and the statistical significance of the r_s identifies the probability of the relationship being found by chance. A low probability ($p < 0.05$) suggests that the results were not found by chance (14).

Table 3. displays the correlation outputs produced when including data from participants in open and closed conditions and shows the correlation outputs from the two subsets of data. Due to the large number of outputs, only the interesting relationships found have been discussed. The researcher considered that those relationships that are interesting are those that differ between open and closed blind conditions i.e., if a significant positive relationship was found between two measures when the blinds were closed but reached a null hypothesis when they were closed.

Measure	All Participant Data			Blind Open (BO) and Blind Closed (BC)					
	Lighting Sensation (r_s)	Visual Strain (r_s)	Identifiable Glare Issues (r_s)	Lighting Sensation (r_s)		Visual Strain (r_s)		Identifiable Glare Issues (r_s)	
				BO	BC	BO	BC	BO	BC
Mean Internal Illuminance (r_s)	$\mathbf{0.56^{**}}$	$\mathbf{-0.18^{*}}$	$\mathbf{-0.25^{**}}$	-0.07	0.08	-0.21	-0.05	-0.20	-0.14
Visual Strain (r_s)	0.06	-	-	$\mathbf{0.44^{**}}$	-0.09	-	-	-	-
Identifiable Glare Issues (r_s)	0.02	$\mathbf{0.42^{**}}$	-	$\mathbf{0.41^{**}}$	0.10	$\mathbf{0.52^{**}}$	$\mathbf{0.31^{**}}$	-	-

* $p < 0.05$, ** $p < 0.01$

Table 3. Correlation matrix of all participant responses and mean internal illuminance levels and participants responses and mean internal illuminance levels between open and closed blind conditions.

3.3.1 Mean Illuminance, Lighting Sensation and Glare

The participants' perception of the lighting and the mean internal illuminance (r_s = 0.56, $p < 0.01$) were positively correlated upon assessing all of the participants' responses. This relationship is presented in Figure 10 with the mean illuminance level on the Y-axis and the light sensation response on the X-axis. The linear line of best fit identifies the difference in relationships when assessing all responses (N = 171) and the responses provided in the blind open (N = 74) and blind closed conditions (N = 97). There was a non-significant correlation between the mean internal illuminance and the participant's light sensation responses when the participant's responses were grouped by blind position (BO r_s = - 0.07, p = 0.54, BC r_s = 0.08, p = 0.04).

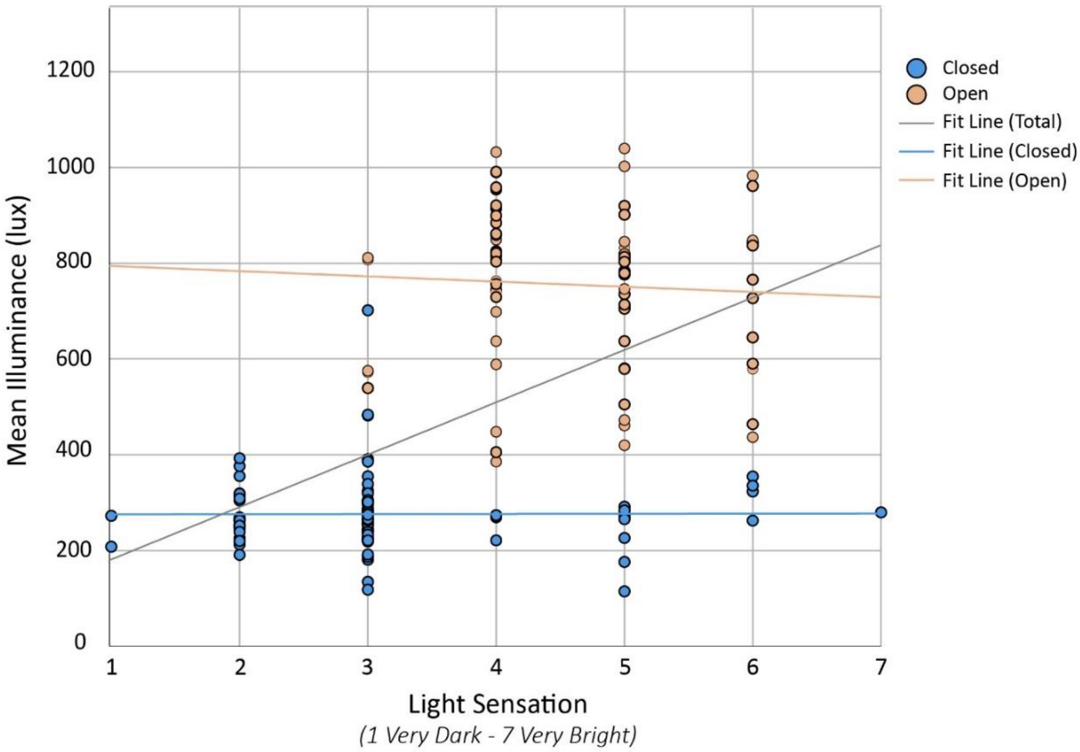

Figure 10. Relationship between mean illuminance (lux) and light sensation responses in the blind closed (●) and blind open (●) conditions (blind closed = 97, blind open N = 74) with lines of best fit.

This suggests that when the data were split between the blind positions, there was an increased variance within the smaller groups of data. Two reasons may explain why this was so. Firstly, glare issues perceived by participants may have resulted in a greater brightness response being reported. Secondly, intermittent cloud cover in the open blind condition may have resulted in a slightly darker perception of the lighting where the mean illuminance may have reflected a higher illuminance as it was an average for the one-hour period that the participants answered the tests and questions within.

The mean illuminance metric in this study was only representative of the light levels on the horizontal plane in the task area and thus was a mean value for the duration of time each participant answered the questionnaire (approximately 1-hour). Therefore, the mean illuminance measured was not able to accurately identify the level of light perceived at eye level by each participant at the specific moment that they responded to the light sensation question. Even though average spot measurements are useful to determine the average light levels experienced, they can only provide an indication of the light levels being experienced at eye level by an occupant. Internal illuminance is highly variable when daylight contributes to the light internally. However, it is generally thought that closing the blinds can help reduce this variability providing more stable (but darker) internal lighting conditions.

Figure 11 presents each participants' lighting sensation response in relation to the mean illuminance measured during the test sessions. The left scatter indicates the participants' responses in open blind conditions and the right scatter shows the closed blind responses. It can be observed that an individual's perception of the lighting conditions does not always positively correlate with the mean illuminance measure. For example, participant B108 in the open blind condition reported that illuminance levels close to 800 lux were perceived as both 'Neutral' and 'Bright'. It can also be observed that there were differences in how sensitive the participants were to the changes in illuminance. These also differed depending on whether the blinds were opened or closed. Interestingly, when reviewing a specific response type between the conditions, there is a notable difference between the illuminance levels related to these responses. For example, when the blinds were closed, several participants identified that the internal conditions were 'Neutral' when the mean illuminance was low (between 200 - 300 lux). However, the same participants in open blind conditions suggested that a neutral lighting sensation response was related to a mean illuminance > 400 lux. This shift in perception between individuals may be related to the participants' expectations of the lighting conditions. When the blinds are closed, they expect the lighting conditions to be darker, therefore there is a shift in their sensation response in relation to the mean illuminance level depending on the position of the blind.

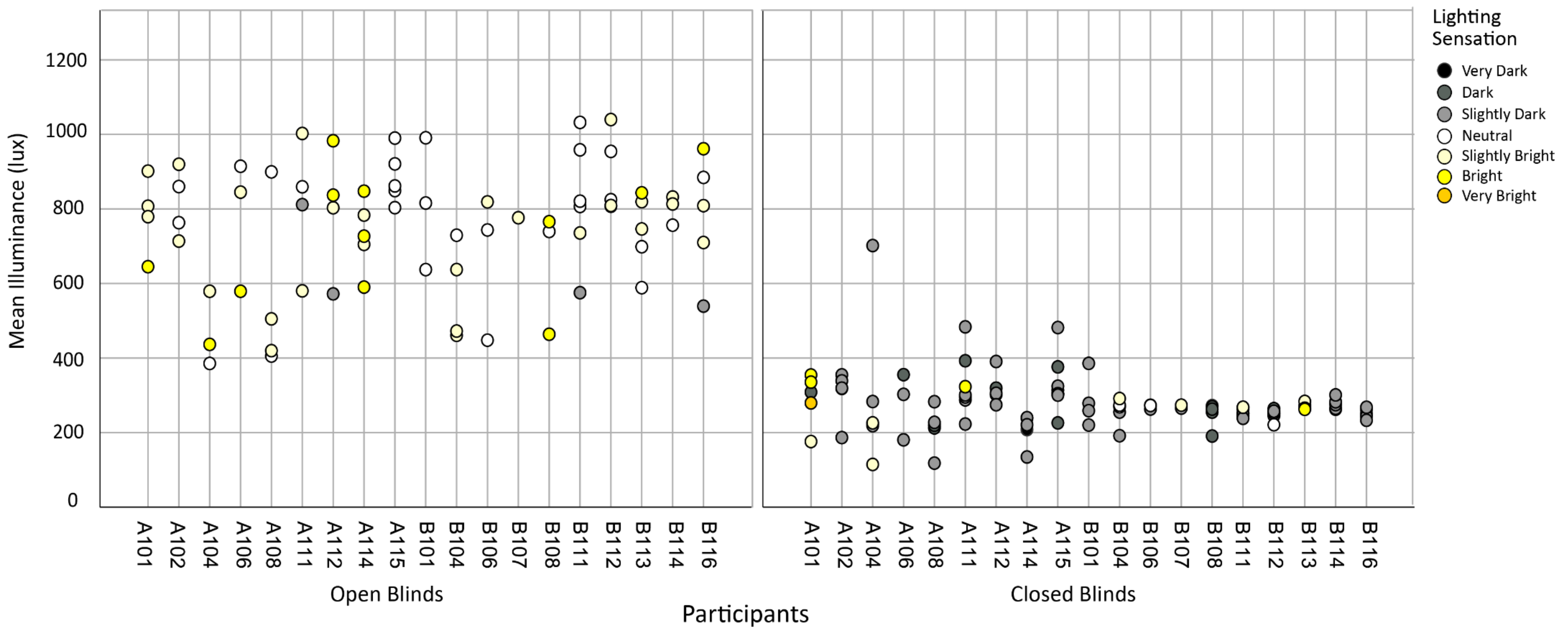

Figure 11. Mean Illuminance (lux) and Lighting Sensation response in both open and closed blind conditions for each participant (blind closed N = 97, blind open N = 74)

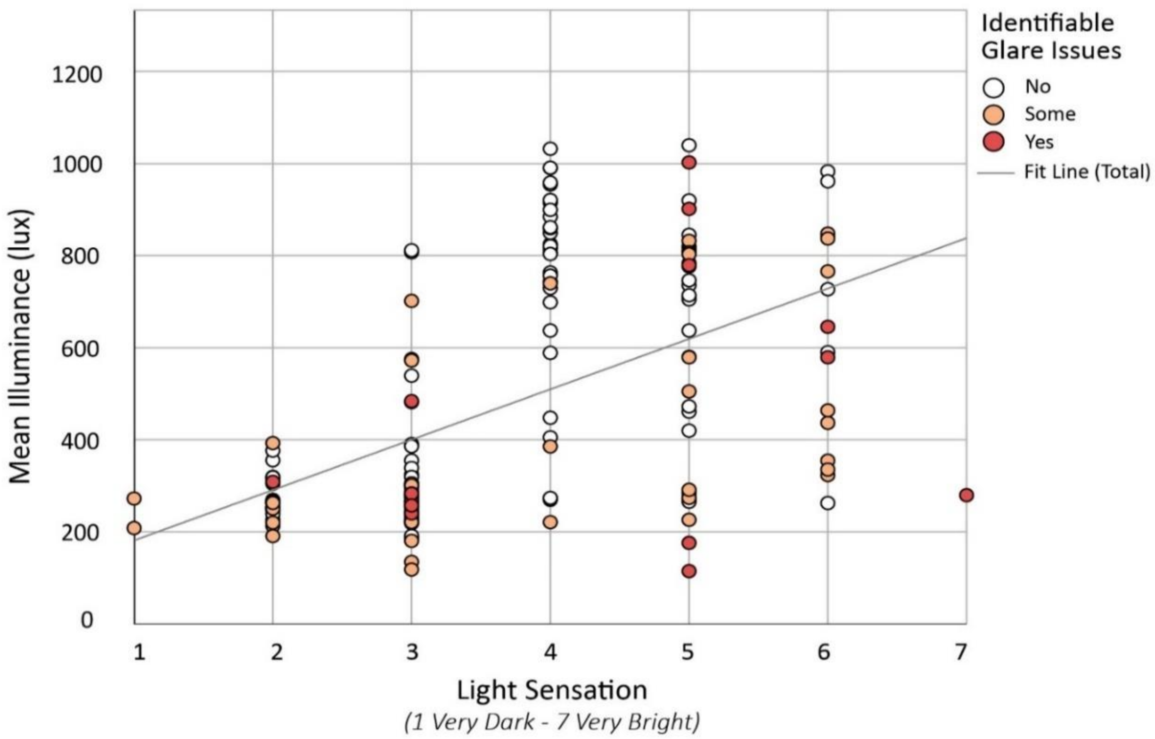

Figure 12. Relationship between mean illuminance (lux), light sensation, and identifiable glare issues with the line of best fit (N = 171).

Figure 12 further investigates whether experiences of glare were responsible for the null hypothesis reached between the mean internal illuminance and the level of brightness perceived. Figure 12 presents the same data in Figure 9, but each data point has been colour coded to identify the participants' glare response. It can be observed that removing the participants that identified 'Yes' or 'Some' glare issues would reduce the scatter in the data. The participants' light sensation and mean illuminance levels were reanalysed without those participants that responded 'Yes' or 'Some' to the glare question and a null hypothesis was still reached in both blind open and closed conditions. This suggests that it was not experiences of glare alone that created the variance in the data and that intermittent cloud cover in the open blind conditions may have also created variance.

Figure 13 also shows that some participants experienced glare issues when they perceived the lighting conditions as either bright or dark. The Spearman's Rho correlation found a positive relationship between the participants' perceptions of brightness in open blind conditions and identifiable glare issues when the blinds were open ($r^2 = 0.41$, $p < 0.01$). However, no relationship was found when the blinds were closed ($p = 0.8$). Figure 13 splits the data in Figure 12 by blind position and shows that generally, when the blinds were open, glare issues were reported when the participants perceived the conditions as brighter. However, when the blinds were closed Figure 13 shows that participants reported glare issues when participants perceived both darker and brighter conditions. This is interesting as generally glare is only associated with brighter perceptions in the environment. Glare issues identified in the perceived darker lighting conditions are likely a result of the contrast in illuminance levels around the visual task. If the peripheral environment had a low illuminance and the illuminated computer screens produced too stark a contrast, this may have been perceived as a glare issue.

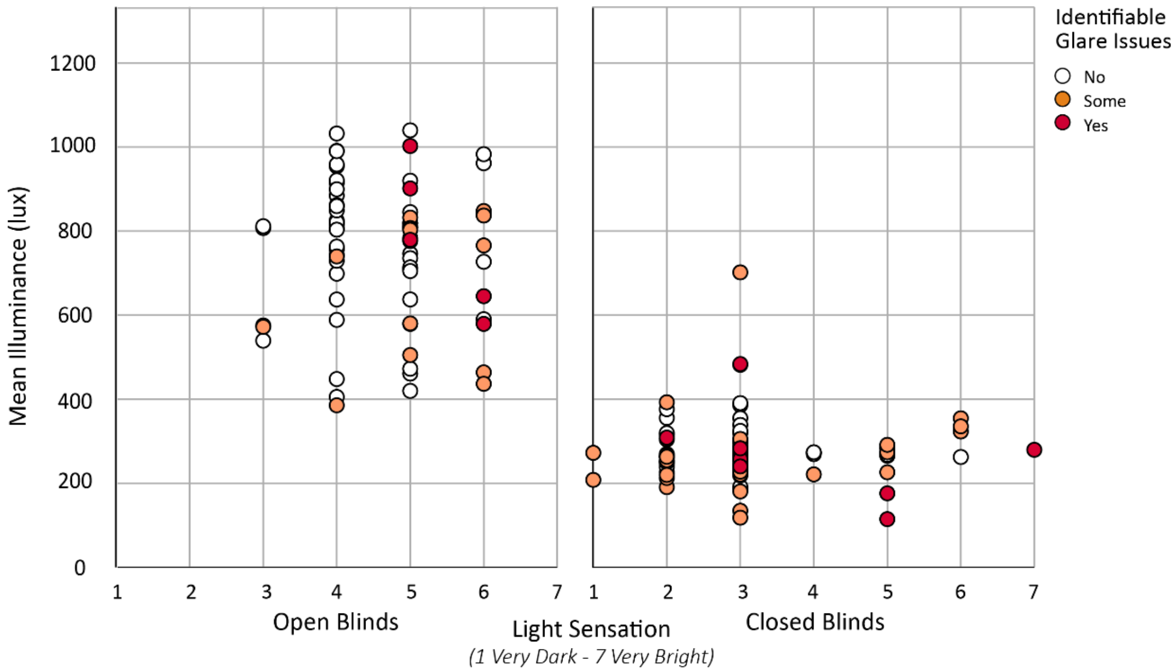

Figure 13. Lighting sensation and identifiable glare issues scatter plot for the blind closed (N = 97) and blind open (N = 74) responses.

Additionally, several participants in the closed blind conditions (A101, A104, A111, B104, B107, B111, and B113) reported 'Slightly Bright' or brighter conditions when the blinds were closed. In total, there were 14 instances where this occurred. The 14 responses were cross analysed to assess whether the participants had also identified glare issues when providing their light sensation response to help explain to why they reported a brighter sensation of light when the blinds were closed. Figure 14 displays the participants in the closed blind conditions that reported 'Slightly Bright' or brighter conditions alongside their glare response and the mean illuminance level on the Y-axis.

'Slightly Bright' or a brighter light sensation were reported on nine occasions when glare issues were also identified and on five occasions no glare issues were reported. On these five occasions, the mean illuminance levels were below the comfort threshold (< 300 lux). Their responses were therefore unrelated to the actual illuminance levels measured or any perceived glare issue and cannot be further explained by the data collected. These may be influenced by individual psychological factors which were not investigated in this study. Potentially these results are anomalous or caused by human error when completing the questionnaire.

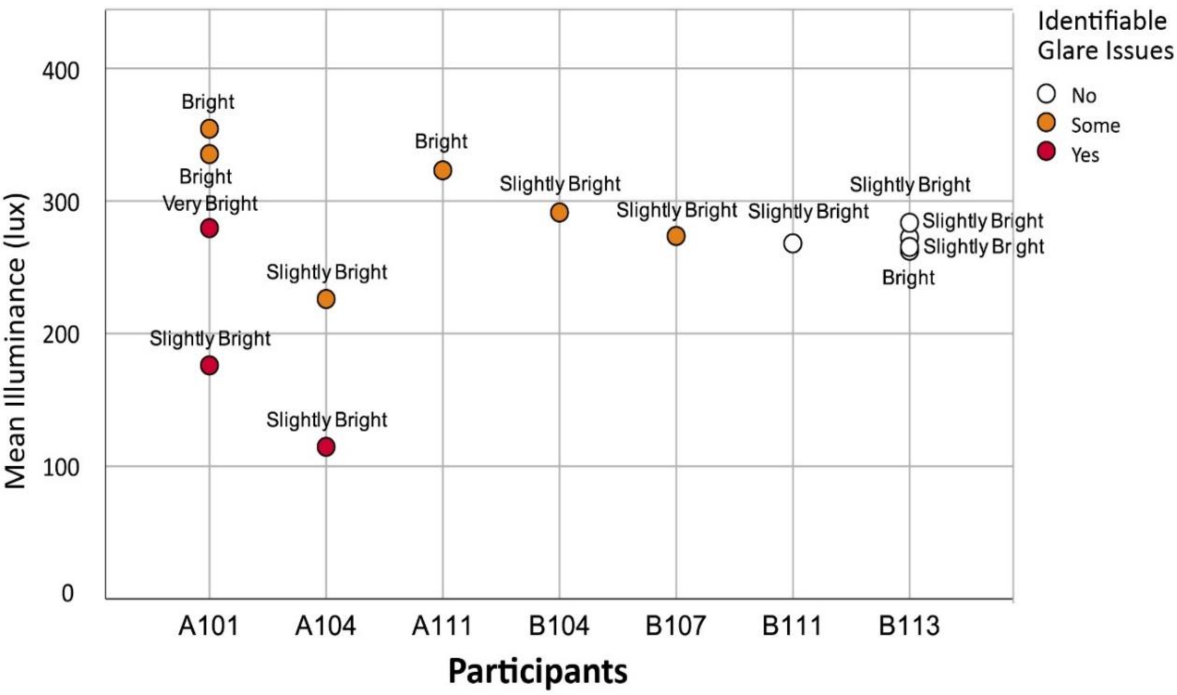

Figure 14. Participants in closed blind conditions that reported Slightly Bright, Bright or Very Bright lighting conditions and the mean illuminance (lux) and their Identifiable Glare Issues response.

3.3.2 Mean Illuminance, Lighting Sensation and Visual Strain

Mean illuminance levels and visual strain had a negative, weak relationship when all participant data was assessed ($r^2 = -0.18$, $p < 0.05$), suggesting that visual strain was reported more frequently when the measured light levels were higher. However, as this was a weak relationship it suggests there is a large amount of variability within the data. Figure 15 shows the variability of visual strain responses in relation to mean illuminance levels. It can be observed that visual strain was experienced when the mean lux levels ranged between 100 and 1000 lux overall.

In closed blind conditions visual strain was reported when mean lux levels were between 100 and 700 and in open blind conditions, they were between 400 and 1000 lux. There were no significant relationships found between mean illuminance levels and perceptions of visual strain when the dataset was evaluated in terms of participants in blind open ($p = 0.07$) and closed conditions ($p = 0.65$).

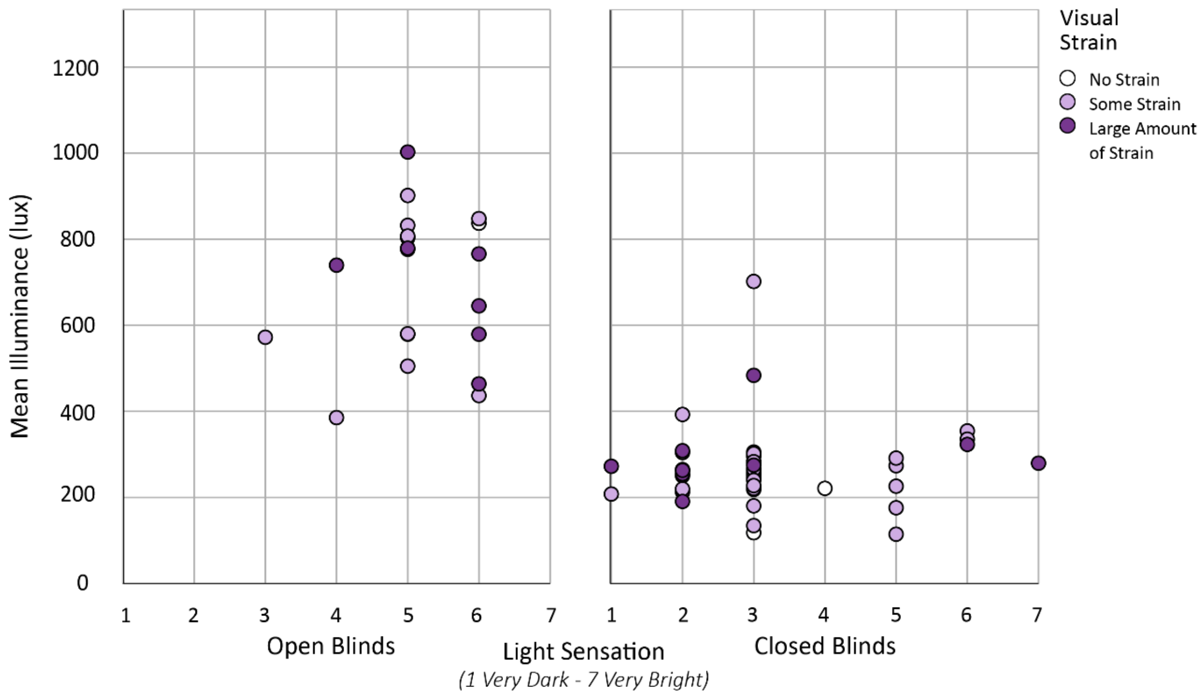

Figure 15. Lighting sensation and visual strain scatter plot of the blind closed (N = 97) and blind open (N = 74) responses.

Figure 15 also displays the relationship between the participants' perception of lighting sensation and their reported experience of visual strain in both the blind open and closed conditions. A non-significant relationship was found between the two variables when assessing all participants data ($p = 0.43$) and participants in closed blind conditions ($p = 0.36$). However, participants reporting of light sensation and visual strain reached significance when responses were assessed in the blind open conditions ($r^2 = 0.44$, $p < 0.01$). The scatter plot shows that when the blinds were open, this led to participants perceiving brighter conditions and a greater magnitude of visual strain was reported. In the blind closed conditions, experiences of visual strain were more independent of their perception of brightness. This does not mean that visual strain was not experienced in blind closed conditions, simply that it was just not related to the participants' perceptions of brightness**.**

3.3.3 Visual Strain and Glare

Visual strain was positively correlated with identifiable glare issues when all participant responses were assessed ($r^2 = 0.42$, $p < 0.01$), when the blinds were open ($r^2 = 0.52$, $p < 0.01$) and when the blinds were closed ($r^2 = 0.31$, $p < 0.01$). This suggests that visual strain was experienced when glare was identified in both conditions. Glare issues are often identified where there is too great a contrast between the visual task and the surrounding environment. Too harsh a contrast between the illuminance levels around the visual task can also result in visual discomfort, resulting in visual strain being experienced (6).

3.0 Conclusion

The use of internal shading is generally thought to prevent glare issues as it attenuates incoming daylight and reduces the variability in daylighting conditions, providing a more stable (but darker) internal lighting condition. However, in this case study there were more reported glare issues when internal shading products were extended. The research carried out could not conclusively prove that the increased reporting of glare issues when the blinds were closed was a result of the position of the blinds causing a harsher contrast between the visual task and peripheral illuminance. However, based on the reporting of ‘Electric Lighting’ and ‘Computer Screens’ being the source of most glare issues in blind closed conditions, this outcome is likely. Incorporating an assessment of how shading products are positioned when POE data is collected may prove valuable in robustly determining the cause of glare issues so that the correct actions can be taken by facilities managers to improve the lighting conditions.

This study also found that the position of shading products created a shift in perceptions of light sensation likely caused by a change in the participants’ expectations of the space when blinds were extended. This suggests that if the position of blinds is not considered during the evaluation of POEs, they may unfairly affect the overall outcomes of POE assessment which could mean the wrong improvement plan is put in place. The incorporation of ‘smart’ moveable shading systems may help rectify issues relating to visual discomfort within offices. Motorised and automated shading systems have been recently incorporated in the Smart Readiness Indicator which identifies how capable a building is in adapting its operation to the needs of occupants and to optimise energy efficiency (15). Motorisation encourage users to interact with shading products more frequently where automated systems operate autonomously depending on the internal or external environment conditions (16). However, the effectiveness of these systems at managing both energy efficiency and occupant comfort is dependent on the control algorithm, integration, and compatibility with other building automation control systems.

This study also showed how horizontal mean internal illuminance levels can be misleading and are not precise or accurate enough to capture the presence of a glare issue within a longitudinal study design. The methodology for calculating the Daylight Glare Probability (DGP) requires significantly more detailed data regarding the visual conditions and therefore was not possible to calculate within this study. However, the shading industry, façade and lighting designers would benefit from further longitudinal case studies that evaluate the DGP and the glare class of shading product installed to give confidence to specifiers in using the tables provided within BS EN 14501 and BS EN 17037.

Lastly, this study also demonstrated how visual strain can be experienced when mean horizontal illuminance levels range between 100 – 1000 lux at head height. This suggest that within the case study building examined visual strain was a result of both too high and too low illuminance levels.

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