Maximum Luminances and Luminance Ratios and their Impact on Users' Discomfort Glare Perception and Productivity in Daylit Offices

Testing the hypothesis: Maximum luminance and ratio recommendations for visual comfort should be specific to the luminous conditions and by accounting for the impact of adaptation, the recommendations will be more accurate.

by

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Abstract

Lighting is an important environmental factor when considering health and safety, visual comfort and workplace design. But how well do we really understand the implications of lighting on these factors, especially in a workplace environment? When one attempts to digest the enormous volume of information of the past century regarding recommended lighting conditions, one begins to see that these recommendations are varied, not extensively tested and often apply to a very limited set of luminous conditions. In a world with daylighting design which increasingly challenges creative and technological boundaries, it is important that the factors and limits which contribute to visual comfort are well understood in order to test these new designs. Daylighting design also becomes important simply from a sustainability standpoint with energy efficiency becoming increasingly important in this age of diminishing natural resources. With an increase in the amount of daylight in buildings spawning from this desire to capitalize on the free and daily renewable light from the sun, difficult and often immeasurable factors such as a view of the outdoors and higher adaptation levels of space users' eyes could very realistically affect the current limits of the human visual system for visual comfort. Visual comfort, limits, which at best are ball park figures, loosely understood and rarely adhered to. This paper documents the testing of 48 test subjects, all of an age where they could feasibly be expected to work in an office environment, in a simulated contemporary office environment with a simulated daylighting window where the luminous conditions and layout were altered to assess the impact of such changes on visual comfort, productivity and different types of user characteristics.

The window is designed so luminances of the window can be changed at will. By comparing subjective assessments of the lighting conditions with test performances, a greater understanding of the luminance limits (maximums and ratios) of the human eye for different contemporary lighting layouts within working-aged populations can be defined. With improved understanding of human tolerances to luminance distributions and lighting conditions which promote visual comfort *and* productivity, designers can begin to give glare prediction with respect to likely effects on these factors. This information would be highly valuable to office based firms who are currently building new or retrofitting premises (to the point where they would likely pay for it as an investment for future efficiency of their firms) thereby proving beneficial to demand for skilled architects, interior and lighting designers. In comparison to the relatively more complicated glare prediction indices involving various factors and calculations, luminance ratio recommendations are an easy to understand tool which with further study could become a powerful method of site and even user-specific glare prediction in the future.

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The researcher would like to thank both ‘PierLite’ and ‘Rexel Lighting’ for their generosity when sourcing the materials for the experiment.

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Contents

1.0 Introduction

The "continuous improvement of environmental factors such as safety measures, aural, visual and thermal comfort and workplace design should be a major aim of every thinking employer or manager and indeed of the workforce and its employee organisations as well" (Willis, cited in Department of Productivity, 1983, p. iii).

Lighting is an important environmental factor when considering health and safety, visual comfort and workplace design. But how well do we really understand the implications of lighting on these factors, especially in a workplace environment? As is discussed in depth further on in this thesis, when one attempts to digest the enormous volume of information of the past century regarding recommended lighting conditions, one begins to see that these recommendations are varied, not extensively tested and often apply to a very limited set of luminous conditions. In a world with daylighting design which increasingly challenges creative and technological boundaries, it is important that the factors and limits which contribute to visual comfort are well understood in order to test these new designs. Daylighting design also becomes important simply from a sustainability standpoint with energy efficiency becoming increasingly important in this age of diminishing natural resources. With an increase in the amount of daylight in buildings spawning from this desire to capitalize on the free and daily renewable light from the sun, difficult and often immeasurable factors such as a view of the outdoors and higher adaptation levels of space users' eyes could very realistically affect the current limits of the human visual system for visual comfort. Visual comfort limits, which at best are ballpark figures, loosely understood and rarely adhered to. This thesis documents the testing of 48 test subjects, all of an age where they could feasibly be expected to work in an office environment (which in New Zealand is typically between 15 and 65 - Statistics NZ (2001a)), in a simulated contemporary office environment where the luminous conditions and layout were altered to assess the impact of such changes on visual comfort, productivity and different types of user characteristics.

Many recommendations exist for the reduction of 'glare' phenomena although as will be shown, these recommendations have varied over the decades and many of the early ones were devised somewhere in the vicinity of 60 – 70 years ago. This paper aims to demonstrate more clearly, under a contemporary setup, the luminous conditions which promote visual comfort or productivity in daylit offices. At the same time the experiment will test some of the recommendations which have been forwarded over the years to test if they truly document the upper limits for acceptable lighting conditions. If not, this paper suggests possible reasons for the differences.

Glare is a difficult phenomenon to quantify or assess. This is because glare is a subjective quality. Space users confronted with similar luminance distributions in their own field of view often experience the sensation of glare to varying degrees and are rarely consistent in their appraisal of different lighting conditions. This is due to various factors inherent to each individual (examples might include eye deficiencies such as myopia, age or height)

> "Glare is a psycho-physical sensation associated with the visual system and like all other such sensations related to the nervous system is not measurable. However, whilst the sensation may not be measurable, the physical parameters associated with the phenomenon can be assessed so that with the aid of statistical methodology the two can be related with a degree of certainty." (Department of Productivity, 1983, p. 19).

Glare is typically classified as one of two main types

- Discomfort glare – This is in generic terms defined as a sensation produced by luminance (brightness) within the visual field that is sufficiently greater than that to which the eyes are adapted. Discomfort glare is usually the result of a high luminance of an insufficiently shielded light source or reflection in the field of vision (Nakagawara, 1990).
- Disability glare – Sometimes called 'veiling reflections', disability glare is the result of a light source of sufficiently high luminance reflecting off a task surface or directly into the eye and hindering productivity - the result of reduced contrast within the task area. This is inherently less problematic to assess because objective 'visual tests' exist which can record performance under particular lighting layouts and luminance distributions.

Discomfort resulting from high luminance or luminance ratios in the user's field of view from inappropriate placement of windows (or roof monitors, skylights etc) can also considerably impair on a person's productive capacity and general sense of well-being in the work-space. Problems with windows in modern office blocks also arise due to the low ceiling heights which only provide sufficient daylight levels for those space users who are working in close proximity to the window walls. This however does not mean that those working deep within such a space are precluded from the possibility of discomfort or disability glare. This is because the luminance of the window even from deep within the space is still relatively high compared to the adaptation luminance of the user's eyes which is a product of the amount of light reaching the eye from the window and other surfaces in the field of view and is much lower (see section 1.4.3). "Illuminance and luminance are independent of the size of a room; they are parameters which are affected by the photometry of the surfaces" (Fontoymont and Fleury, 1986, p. 337).

However, daylight is an important factor in building design even in modern office blocks where the majority of the floor area is artificially lit; not just because it increases energy efficiency by reducing the need for such artificial sources and helps provide a satisfactory quantity of illumination but because "for the majority of occupants the window remains that *vital link* with the outside world" (Department of Productivity, 1983, p. vii). In addition,

"daylight has qualities that can make work easier, as well as creating enjoyable interiors with variety in brightness and the refreshment and relaxation of a view outside. Side windows provide directional light which gives good three-dimensional modelling for tasks. Also, the appearance daylight gives to colours is considered excellent for most purposes" (Bell and Burt, 1995, p. 28).

However, it is exactly this use of daylight which might create serious glare issues impacting on both the health and productivity of space users and why a good level of understanding about the impact of different window luminance levels and orientations is vital to enjoying all the benefits mentioned above while limiting the negative effects of glare associated with the very same daylight apertures.

1.1 Historically relevant research and aim of this research

As previously stated, glare is a complex phenomenon and as such is inherently difficult to predict. Its effects are also hard to quantify although researchers have tried to identify and quantify the various factors which should be limited or controlled (see section 1.2) to reduce the impact or at least the likelihood of lighting conditions which might reduce comfort or productivity. Currently recommended standards for visual comfort in office-based environs using VDUs (i.e. the absence of discomfort glare) include:

a) Luminance ratios in the field of view exceeding 100:1 should not be tolerated (Osterhaus, 2002)
b) A luminance ratio of 40:1 should not be exceeded although this more than likely applies to artificial lighting installations as a possible exception to this rule is noted as crystal chandeliers (Egan, 1983). Applicability to only artificial lighting installations is made more likely as the same list of recommendations suggests a ratio of 50:1 will highlight the object/surface to the point it excludes everything else in the field of view.
c) Luminance ratios of the order of 10:1 are an upper limit for visual comfort (Veitch, and Newsham, 2000).
d) A luminance ratio of 3:1 & 10:1 between the task & nearby surroundings, and the task & more distant surroundings is desirable for visual comfort (Osterhaus, 2002).
e) The maximum luminance in the field of view should not exceed 1500 cd/m^2 (Osterhaus, 2002). This is approximately 12 – 15 times brighter than an average CRT or LCD computer screen.

It is important to note the difference between the terms 'luminance' and 'brightness' which are often confused with one another.

"'Reflected luminance' is the photometric measure of 'brightness' of an illuminated opaque surface, and is the product of 'illuminance' and 'reflectance'. It is analogous to the water bounced off of a sponge. 'Subjective brightness' is the visual sensation equivalent of 'luminance' and is influenced by such factors as the state of adaptation in the eye as well as luminance. (While the term 'brightness' is often used when referring informally to measurable luminance, the preferable term for photometric quantity is 'luminance', thus reserving 'brightness' for the subjective visual sensation)." (Moore, 1986, p. 3).

However, some of the recommendations were initially devised during the 1940s - more than 60 years ago - and little extensive study has been done to test maximum luminances and luminance ratios in a modern context which we now face, with completely different luminous environments than those of the 1940s (fluorescent office lighting, LCD screens, LED technology, innovative daylighting methods). Particularly where fenestration is concerned:

"The size, proportions, details and positions of window openings are fundamentally to do with the amount of light entering a building, its distribution and quality. Historically they have been conditioned by the materials and technology available at the time" (Bell & Burt, 1995, p. 3).

Studies have shown that productivity decreases with increasing surface luminances in the field of view (Osterhaus, 2002). However, studies also suggest that luminance ratios of 10:1 or more are necessary to stimulate visual interest thereby increasing productivity by avoiding dull environments which encourage a loss of interest in the task (Veitch and Newsham, 2000). With regard to the 1500 cd/m^2 recommended maximum luminance; an overcast sky as seen through an office window can have a luminance higher than 10,000 cd/m^2. 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 (lighting layouts). A study into the impact of different transmittance levels of electrochromic glazing (Inkarojrit, 2006) on the luminance ratios in offices between the VDT (visual display terminal) and other surfaces which may be immediately adjacent to the task or more remote (e.g. table tops and walls etc) showed that with just a 50% glazing transmittance, luminance ratios were well in excess of currently recommended comfort level ratios.

Indeed my own studies (Linney, A, 2005) of artificial point glare sources in the field of view, which presented a number of ratios in excess of 100:1 still had many users assessing the conditions as comfortable. This does not coincide with those early findings mentioned previously and suggests that the human eye is in fact a robust visual system which can cope with a large range of luminous conditions (given time and adequate adaptation levels). Robbins (1986) spoke of how "the human eye can function quite well over a wide range of luminous environments, including starlight (0.03 cd/m2) and clear sky (10,000 cd/m2); however, it cannot function very well if such extreme levels of brightness are present in the field of view at the same time” (p. 235). Osterhaus (2002) put forward the possibility that office users could even be comfortable and productive under luminance ratios approaching the upper limit of the human adaptation range (1000:1) if a desirable view of the outdoor environment is available. This concept is illustrated in the image below in paper by Osterhaus and Madsen (2005).

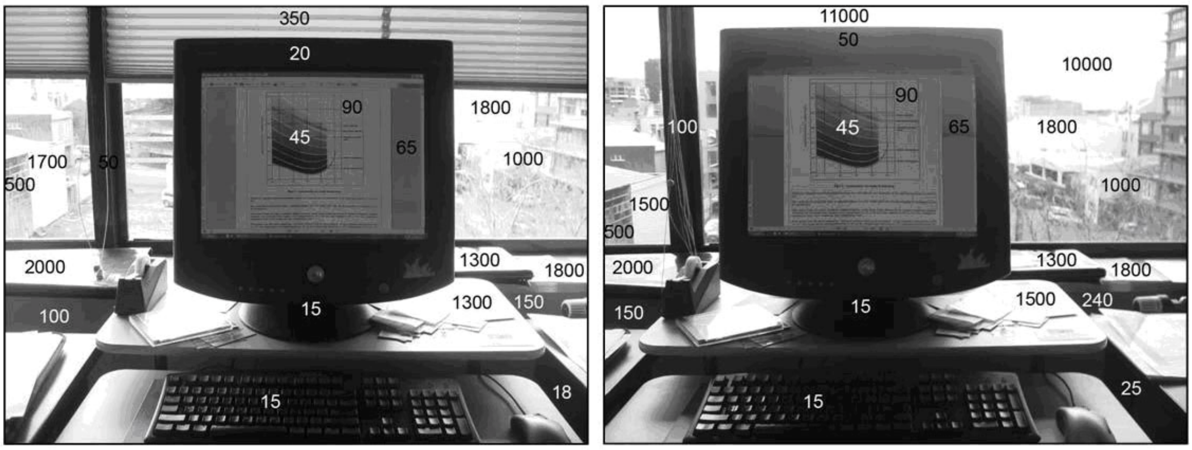


Figure 1.01 Examples of luminance measurements and visibility of objects in relation to a computer workstation

These luminance ratios are far from the traditional 10:1 and the researcher (Osterhaus, 2002) makes it clear that further research is required to establish such limits or the impact on productivity (although results from the studies survey support the asking of the question). All of this illustrates the difficult nature of studies of preferred luminous environments and visual comfort. With a better understanding of human tolerances with respect to various luminance distributions and maximum luminance values in the field of view, designers and office users alike could benefit. This is why this experiment examines luminances and luminance ratios which are outside these currently recommended values. The aim is to assess the impact of higher values which could arguably be acceptable but which our presently limited knowledge and many varied theories on the subject prevent us from truly understanding.

As has been shown, productivity in the workplace is at least in some capacity linked to the quality of the lighting conditions. Therefore, it is important that the quality of office lighting is of a standard which promotes a good level of productivity and visual interest. Designers currently make use of rendering packages which can retain the high dynamic range of luminance values represented by each pixel in the image (i.e. the actual brightness of the surface in the rendering rather than simply relative pixel intensity). By positioning the camera in a rendering program to display an image which represents the space users’ likely field of view, designers can then calculate (given careful definition of the materials within the rendering package) the maximum and minimum luminances in the field of view and the subsequent luminance ratios. Couple this with an improved understanding of the luminous conditions which promote visual comfort and higher productivity levels, the designers can make this an effective tool to improve the quality of their work with respect to the likely effect on productivity and visual comfort levels. This sort of information would be highly valuable to office based firms that are currently building new or re-developing existing premises (to the point where they would likely pay for it as an investment for the future efficiency of their firms) thereby proving beneficial to the demand for skilled lighting designers, architects and designers.

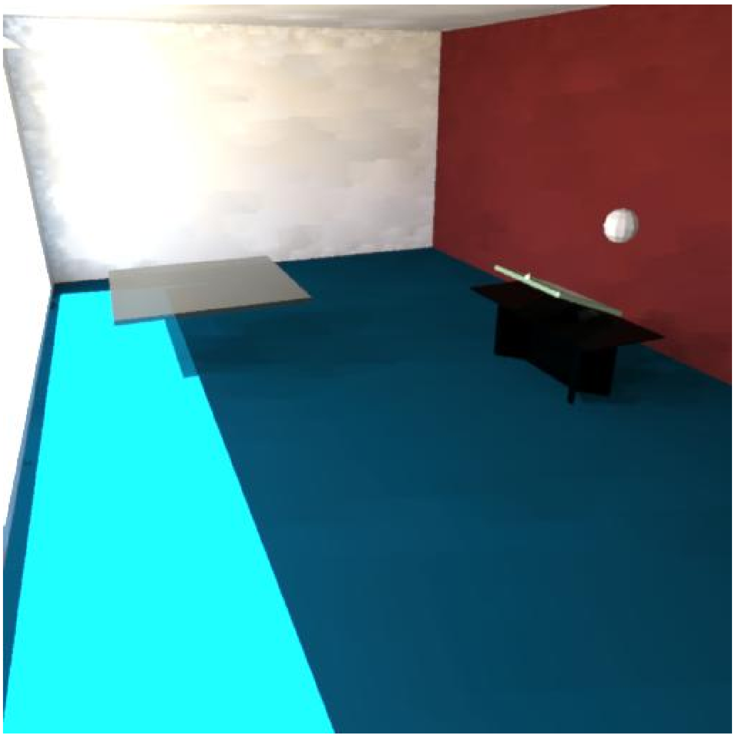


Figure 1.02 Example of CAD rendered image (using Rayfront) which retain high dynamic range data

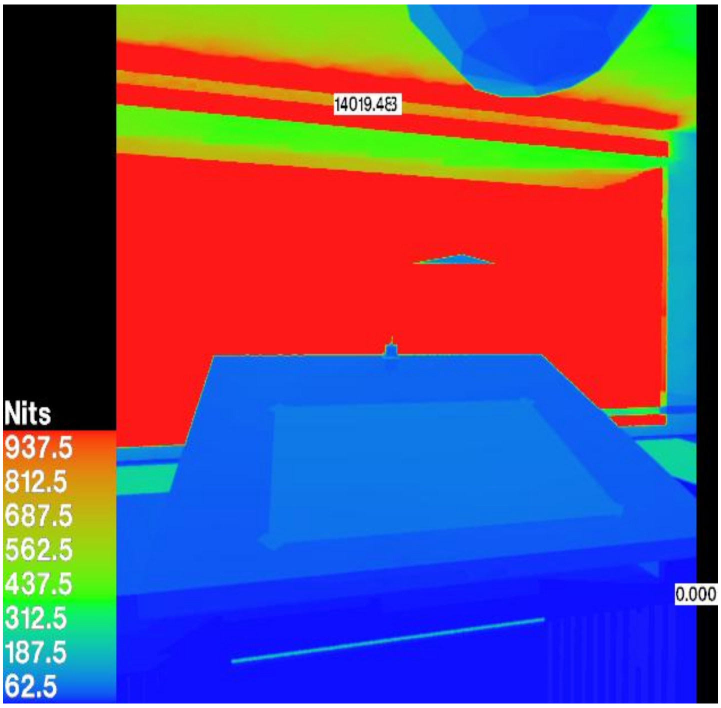


Figure 1.03 Example of rendering of users' field of view in false colour displaying high dynamic range data

The data from this research will be highly useful to lighting designers, architects, interior designers and office users alike and as such it is well worth the time and money required to explore the issue in depth.

"To get the best and most economical results, the design of daylighting and electric lighting must be considered jointly, with the architect and lighting engineer working together from an early stage" (Bell and Burt, 1995, p. 28).

1.2 Luminance Ratios in Glare Assessment Indices

A number of prediction indices for the likely degree of discomfort glare perception exist. Each formula relates the factors which are deemed important for the perception of glare and uses exponents to weight each factor appropriately. Some indices show stronger correlations with the prediction of degree of discomfort glare perception from artificially lit environments and others with daylit environments.

The important factors typically included in the assessment of discomfort glare are defined as follows:

The **solid angle (ω):** In the case of artificial lighting, it is the 3 dimensional angle of light projected from the source onto an imaginary sphere as seen at the eye. In the case of daylighting it is the amount of visible sky as seen through a window from the users' point of view. It is measured in steradians.

The **glare source luminance (L_s):** In the case of artificial lighting it is usually the filament or lamp itself (if visible from the users' viewpoint). With day-lighting, it is the maximum luminance as observed from the users' viewpoint, typically found at or through a window.

The **background luminance (L_b):** It is the average luminance in the field of view with the glare source(s) removed. The ratios mentioned above are to do with the difference between the glare source and background luminances. Background luminance helps set adaptation levels of the eye but is not the only factor. This is a product of *all* the light which reaches the eye (including the impact of glare source luminance L_s) so the wisdom of this definition with regards to luminance ratio recommendations is sometimes questioned since the current definition does not account for the impact of the glare source itself on adaptation. Alternative definitions for background luminance levels incorporating vertical illuminance at the eye of the user to account for this have been used in later indices.

The **position within the field of view ('Ψ'):** The glare formulae which are outlined below all incorporate some form of complex position function to take account of the fact that the location of the glare source in the field of view has a bearing on its impact on glare perception. FINDGLARE (see 1.2.5), does not always account for the location of a glare source when locating potential sources. With further understanding of how position affects perception of the impact of glare, tools like FINDGLARE could be made more robust making it more useful when used in conjunction with luminance ratio recommendations. This would reduce the need for more complicated calculations with the output data.

In general these factors can be related in the following way:

$$G = \left(\frac{L_s^e \cdot \omega_s^f}{L_b^g \cdot f(\Psi)} \right)$$

Figure 1.04 General glare formula arrangement

The exponents give a suitable weighting to each of the various factors and vary according to the specific glare formulae. Below are some commonly used glare indices indicative of the types of glare prediction models built into some rendering packages. The methods which were used to derive these relatively complicated indices determine their effectiveness in predicting glare likelihood under different conditions. Some formulae suit singular and point sources and others have been re-worked to include situations with multiple or large sources (such as windows).

1.2.1 British Glare Index (BGI)

$$BGI = 10 log_{10} 0.478 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \omega_s^{0.8}}{L_b \cdot P^{1.6}}$$

Figure 1.05 BGI formula

The BGI was developed at the British Research Station (BRS – now British Research Establishment, BRE) more than 50 years ago. It is an empirical formula based upon similar subjective assessment options as used in this experiment (detailed in section 2.7.2). It does take account of more than one source (given by 'n') but only suits point sources with very small solid angles. L_b in this formula is taken to be "that uniform luminance which produces the same illuminance on a vertical plane at the observer's eye as the visual field produces by inter-reflected light alone. It is numerically equal to the vertical illuminance at the eye [adjusted by Pi to form an average field of view luminance] from inter-reflected light" (Bedocs and Simons, 1972, p. 80).

The same report by Bedocs & Simons suggests discrepancies in glare prediction due to several arithmetical errors (amongst other factors), one of which is that L_b is incorrectly calculated. As previously stated, the original definition does not incorporate the impact of the glare source itself on adaptation levels. As such, daylit installations where the glare source(s) (the window(s)) tend to also set the adaptation because of their strong effect on overall illumination levels would have difficulties using this index as a design tool. This problem could also extend to offices with wide angle or indirect component luminaires which affect adjacent surface illuminance (which helps set adaptation luminance levels). However, in the ten years following its introduction it was praised by Bedocs and Simons (1972) who commented that through the efforts of Hopkinson and Petherbridge it “enabled the factors which control glare to be isolated and quantified, and it has been valuable to the designers of installations and luminaires. There is no doubt that the quality of electric lighting installations has been improved as a result of its introduction” (p. 80) even though it is regarded as the least accurate of the indices illustrated here. Petherbridge and Hopkinson (1950) make it clear that the index should only be used as a “rough guide as a form of specification or recommendation” (pp 15, 39) and even go on to suggest that any recommendations should be specific to particular buildings. It quickly becomes apparent however that even during these early days of glare prediction indices, researchers believed the ratio between the glare source and background luminance was an important consideration.

1.2.2 Daylight Glare Index (DGI)

$$GI = 10 log_{10} 0.48 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega_s^{0.8}}{L_b + 0.07 \omega_s^{0.5} L_s}$$

Figure 1.06 DGI formula

The daylight glare index is a modification of the BGI equation designed to predict glare from large sources (e.g. a window). The equation was originally derived from experiments which used fluorescent tubes behind a translucent white screen to simulate a daylighting window (which was also the technique used to simulate a daylighting window in the experiment described in this thesis). This may be why the predictions showed the strongest correlations with windows up to the size of the 1500mm fluorescent tubes used in the artificial window in the experiment and predictions became progressively more erroneous as the window sizes exceeded this (Hopkinson, 1972). The formula relates two factors as a direct function: the size of the window and the luminance of the visible portion of sky as seen through it and as an inverse function: the brightness of the interior environment (i.e. glare probability increases as window size and brightness go up and decreases as the brightness of the interior goes up). In this we begin to understand the complexity of the glare prediction in daylit environments. A larger window would increase the likelihood of glare but at the same time, a larger window would have a greater impact on the background illumination level in the space which reduces the likelihood of glare. Subsequently the correlation between predicted glare and assessment is not as strong as for artificial lights with relatively small solid angle. This is at least partially due to the fact that large light sources tend to set the adaptation level in a room (i.e. the difference between the average room luminance and the glare source is smaller). It could also be due to far less objective measures, such as the view out of the window which increases user tolerance of the window as a glare source (e.g. the same luminance distribution but from an artificial lighting setup is subjectively assessed as more disturbing by users despite the same prediction value from glare indices). Although it is important to note this increased tolerance is limited to mild degrees of glare (Hopkinson, 1972).

The difficulty this view factor adds to the already complex process of glare prediction in daylit environments was described by Hopkinson (1972) from anecdotal evidence acquired from experiment participants' comments during subjective glare surveys.

"Of those parameters not included in the glare formula (window brightness, room brightness, size of window, position of window) the most frequently occurring comment was about the view outside the window. The view outside is undoubtedly a mediating or an enhancing factor in determining the glare discomfort from the window. The comments showed that there is an underlying conflict in making an assessment in a highly glaring situation if the window has a pleasant view or one with a great deal of interesting information. In such circumstance, the observer would extend his tolerance level to discomfort, even thought the view is not actually reducing the glare. In other cases, observers commented that objects in the field of view added to the discomfort glare, especially if they were reflecting light from their surfaces. Altogether, the view outside was shown to exercise a marked, but not predictable effect on the probable degree of glare discomfort, and therefore it adds the variance of judgement" (ibid p. 212).

While this not only identifies how complex glare appraisal for visual discomfort is in daylighting, it also suggests that experiments of the type used to develop these daylight indices with artificial windows will have a limitation for predicting borderlines of comfort/discomfort (BCDs) and maximum luminances because in actual daylit environments the view of the exterior environment (which is absent in these artificial window experiments) will have at least some mitigating effect on glare appraisal i.e. BCD levels may actually be higher than laboratory experiments find. With regards to how the luminance ratios were determined in this variation of the glare prediction indices, the source luminance (L_s) was a product of the global illumination at the plane of the aperture and the background luminance (L_b) of the exterior and interior reflected illuminances. This was a way to account for the overall lighting levels in the space (impact from glare source inclusive) which would affect adaptation levels which designers knew to be greatly influenced by windows. Windows tended to set the adaptation level of the eye and subsequently, how disturbing the window luminance itself was. This move acknowledges the complexity of glare assessment in daylit spaces (and that it was not just the ratio between glare source luminance and background luminance with the glare source removed) although it still did not account for exactly how much light reaches the users' eyes.

1.2.3 CIE Glare Index 'CGI'

$$CGI = 8\,log_{10}\, 2 \cdot \frac{\left[1 + \frac{E_d}{500}\right]}{E_d + E_i} \cdot \sum_{i=1}^{n} \frac{L_s^2\, \omega_s}{P^2}$$

Figure 1.07 CGI formula

This is the first formula which began to deal with the illumination at the eye from E_d and E_i (direct and indirect illuminance components respectively) *including* the glare sources' impact on a vertical plane at the subject's eye as a means of assessing adaptation levels of the eye. The formula was an improvement made by the CIE, to correct for some of the inconsistencies the earlier BGI formula had accounting for multiple sources. The installations used in the experiments were illuminated to 500 lux using flush-mounted ceiling luminaires with a total luminous flux of 2700 lumens (Lowson, 1981). The effulger where this thesis' experiment was conducted uses a similar setup (see section 2.2).

1.2.4 Unified Glare Rating 'UGR'

$$UGR = 8\log_{10} \frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \frac{L_s^2\, \omega_s}{P^2}$$

Figure 1.08 UGR formula

Another development by the CIE, the UGR combined parts of the CGI & BGI formula (in particular the BGI's position function) to assess artificial lighting installations. Arguably the most accurate for the way it was developed from combining other existing incarnations, the UGR only deals well with very small glare sources. This is borne from the way the formula draws a distinction between background and glare source luminance. The field of view is divided up into two categories of either 'glare source' or 'background' which creates difficulties in dealing with indirect lighting or large area glare sources (because the edges of the glare source and background are not well defined and large area glare sources such as windows have a strong impact on the illuminance of surrounding surfaces and hence adaptation levels of users' eyes).

Sendrup (2001) defines the background luminance: "L_b, is determined as that uniform luminance of the whole surroundings which produces the same illuminance on a vertical plane at the observer's eye as the visual field under consideration excluding the glare sources" (p. 243).

Because the formula was designed with interior lighting in mind, the position index applies for directions which are above the user's line of sight (where installations such as offices would typically locate luminaires e.g. the ceiling). This potentially causes further disparities in glare predictions for layouts with large area glare sources (e.g. a curtain wall) as the glare source extends well below the users' line of sight or fills the majority of the field of view if a user is facing the glare source directly. Recent studies have attempted to mitigate some of these factors to make the UGR method suitable for larger area glare sources, lower contrast glares sources and glare sources which are not necessarily above the user line of sight. The ‘General Unified Glare Rating’ (or ‘GUGR’) (Sendrup, P, 2001) modifications include a re-definition of L_b to include the impact of the glare source (which reinforces the notion that accounting for the glare source in the definition of any background or adaptation luminance value is a prudent measure especially if dealing with large glare sources) and adapting the position index to include glare sources below the line of sight. Tests were conducted with varying degrees of correlations using a large simulated glare source not unlike the technique used in the development of the DGI formula and in this thesis’ experiment (fluorescent lamps behind a white semi-transparent screen). The fact that all these indices regardless of their fortè areas incorporate a complex position and solid angle function confirms that the position and size of the glare source, not *just* its luminance are important factors in glare assessment.

Einhorn (1998) suggests that the key to a successful glare assessment method is a technique which “(a) avoids mathematical anomalies or ambiguity and (b) is simple enough to be acceptable for practical use” (p. 89). *Simple* is at odds with the obviously complex nature of glare science. The luminance ratio recommendations mentioned previously are a relatively simple method for quick checks although they are unaffected by either size or position of the glare source(s) which the indices discussed here have clearly illustrated as important. Results from this thesis into the implications of different glare source positions and large area glare sources would help with the relevance of the relatively simpler luminance ratio recommendations.

1.2.5 'FINDGLARE' and 'EVALGLARE'

Other tools for glare prediction also exist which take some of the complication out of using the relatively complicated glare indices discussed previously.

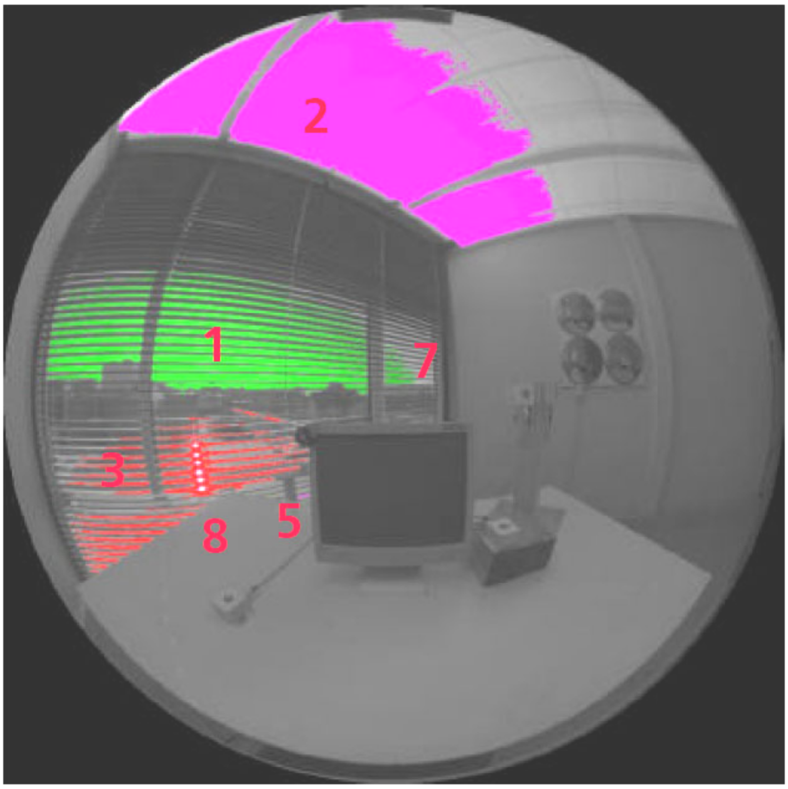


Figure 1.09 Example of fish eye image used by FINDGLARE

These tools use rendered images or photos of a likely user field of view taken with a luminance mapping camera (see figure 1.09). The tools then use the high dynamic range data (the luminance values for each pixel which are retained in many rendering packages unlike digital photographs which record relative pixel intensity on a scale between completely white and completely black) to calculate the average pixel luminance in the scene. The tool then uses an arbitrary luminance threshold or value 'X' (this is typically '7' according to Lawrence Berkeley National Laboratory) and identifies any pixel in the scene which is above the luminance threshold or 'X' times brighter than the average pixel luminance in the scene or 'X' times brighter than the task area luminance (Wienold et al, 2005) as a potential glare source. While one can argue that this technique is relatively easier to use than other methods of identifying where potential glare sources area, it does not account for the individual characteristics of any one luminous condition nor does it indicate the likely severity of the glare source from the raw output data.

No	pixels	x-pos	y-pos	L_s	Omega_s	Posindx	L_v	L_t	E_vert
1	14472	216.564907	442.473736	13107.75979	0.209413	2.144232	7755.061928	3142.938458	9772.462088
2	46459	368.149613	664.07898	9525.377624	0.58812	16	7755.061928	3142.938458	9772.462088
3	5485	180.177804	305.483578	11745.91399	0.075856	1.000051	7755.061928	3142.938458	9772.462088
4	5	270.206071	291.401041	6269.334165	0.000076	1.000051	7755.061928	3142.938458	9772.462088
5	17	301.300419	291.001381	7674.734499	0.000264	1.000051	7755.061928	3142.938458	9772.462088
6	1	306	365	6197.875	0.000016	1.000051	7755.061928	3142.938458	9772.462088
7	315	395.792346	416.896021	6440.339508	0.005135	1.188712	7755.061928	3142.938458	9772.462088
8	163	196.383179	317.815929	573283.0132	0.002351	1.000051	7755.061928	3142.938458	9772.462088

Figure 1.10 Example of output data from EVALGLARE

The output data (see figure 1.10 for an example) from EVALGLARE can then be put into the different indices for glare prediction calculations. The technique can be used effectively in the early design phases of a building project to identify which spaces have a high potential for glare sources or could benefit from a re-design while it is still relatively cheap to do so. This thesis which looks closely at luminance ratios could be useful in beginning to identify the sort of ‘X’ values which should be used based on the specific characteristics of an office layout or the luminous condition (perhaps a database of recommended ‘X’ values based on such characteristics as layout, window/lamp position, size etc) rather than a single arbitrary value which in reality could very plausibly need to be higher or lower [because of the office layout or luminous conditions]. Alternatively the raw data itself can be analysed simply from a luminance ratio stand point but still be as useful as the more complicated calculations because the impact of the specific luminous conditions is better understood. Either way, results from experiments of this nature will improve the effectiveness, simplicity and accuracy of quicker and simpler glare prediction techniques making them more likely to be employed by the average designer.

2.0 Experiment Calibration

The experiment exposed test subjects to a large light-box that simulated a large area glare source in an office wall with a range of luminances. Prior to commencement of the experiment, the luminous conditions and office layouts that each test subject would be exposed to were carefully documented. This section details each of these facets of the experiment. Foremost the layouts and luminous conditions were documented so that the overall subjective visual comfort assessments under each condition could be analysed in relation to how close the luminous conditions were to recommended luminances and luminance ratios and secondly, so that productivity declination in relation to luminous conditions could be analysed.

2.1 Sample Size and Statistical Power

Firstly, glare science is a 'ball-park' science. As discussed, glare is a subjective quality and test subjects are rarely consistent in their appraisal of different lighting layouts. Einhorn (1998) stated in his paper on the merits of the UGR tool that "the glare sensitivity of any individual is vague and measurements are not precise; this is borne out by large standard deviations and the poor reproducibility of glare observations".

A study into post-occupancy evaluation (POE) of daylight in buildings (Hygge and Loftberg, 1999, p. 9) suggested that it is preferable for the group of users in the test sample to be as "homogenous as possible" (e.g. a diverse range of ages, educational backgrounds and similar number of each gender). For a "between person comparison" or analysis of one particular factor over two different sample populations and conditions about 30 persons per group is recommended. For a "within persons situation" or where all participants will be exposed to all the different conditions; 15-20 persons are recommended although "If the groups are less homogeneous larger groups are needed to decrease the variance and to detect real differences" (ibid). Since this experiment is the latter (all test subjects will be exposed to all the lighting conditions) it first appeared likely that a sample size of at least 15-20 would be appropriate. The statistical power of a survey is principally a factor of the sample size and the population size. In statistics, the population size becomes statistically irrelevant after 20,000 people as the variance in margin of error becomes insignificant after this point (Raosoft, 1996 - 2007). The New Zealand census data (Statistics NZ, 2001b) shows that the number of people in the working-age population who could reasonably be expected to spend time working in front of a computer (the sciences, teaching professionals, office clerks etc) is approximately 532,000 (see figure 2.01). The population used for statistical power analysis uses New Zealand figures since the test population were sampled from people working in a New Zealand office (or similar) at the time of the experiment. In truth, since the human visual system is essentially the same no matter where in the world a person comes from or works, the population size could even be all working age office workers regardless of locale. Either way, the population size is easily greater than 20,000.

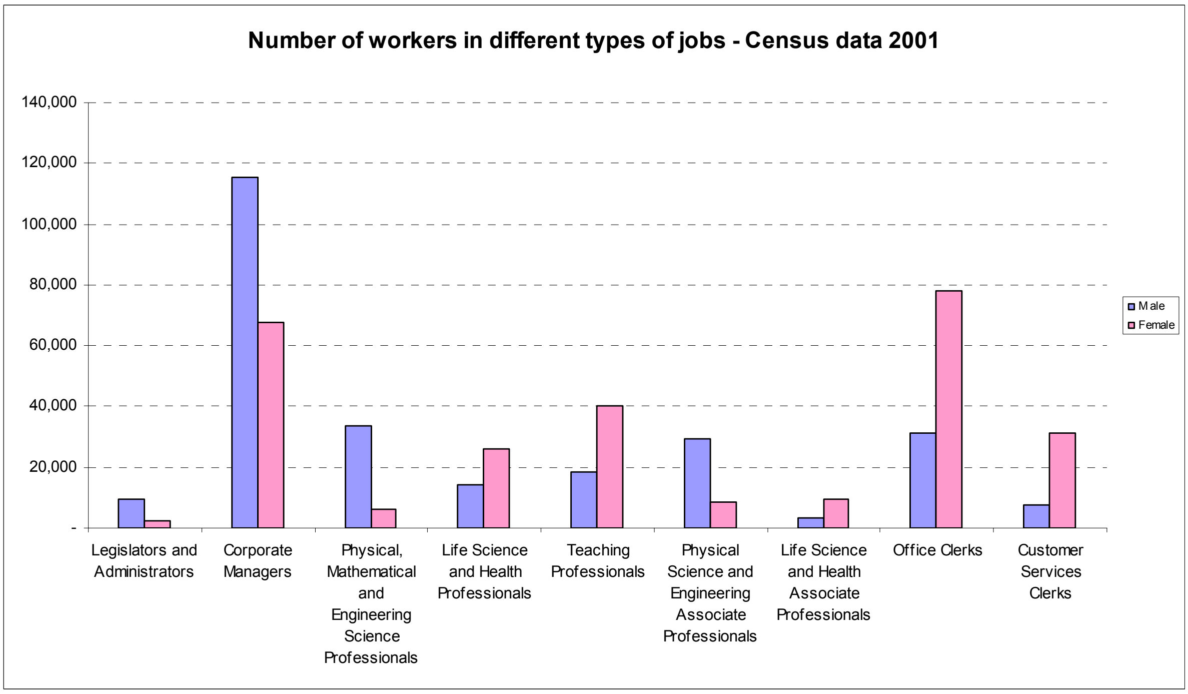


Figure 2.01 Number of men and women in various occupations where the use of a VDU could reasonably be expected based upon 2001 New Zealand census data

Because this number is much larger than 20,000 it is acceptable to assume for the purpose of statistical power calculations that the population size is infinite. With the population size determined, the next thing to establish is the sample size. Because glare science is so uncertain it is unlikely even with a larger sample size than previous glare experiments that the standard deviation would be less than 5% (the average will likely be a factor of a wide spread of responses ranging from satisfactory to intolerable - see section 3.0). Therefore a likely margin of error of one step along the subjective assessment continuum has been specified as tolerable for sample size calculation. This allows for the fact that a sizeable standard deviation is likely due to the nature of glare science while keeping the likely true average response for the entire population within one response degree (see examples below) of the experiment average. One response degree approximately equates to a margin of error of +/- 14.2%. Using two independent web-based sample size calculators (Raosoft, 1996 – 2007; Dimension Research, 2005) and inputting a confidence level of 95%, the experiment requires a sample size of approximately 48 subjects.

That is to say, if we assume an infinite population and use a sample size of 48 subjects, we can be 95% sure that the true mean for the entire population lies at the mean for the sample size, plus or minus 14.2% (or one subjective response degree). Or, if the average subjective response for visual comfort in a particular test setup of 48 subjects is a ‘3’, then we can be 95% sure that the true mean for the entire population lies between a ‘2’ or a ‘4’ (see section 2.7.2 for definitions of these points).

To put this sample size into perspective, a number of similar studies with subjective assessment of visual comfort were looked at. Wienold & Christoffersen (2006) conducted an experiment for glare prediction in daylit environments using CCD cameras (a camera which retains the high dynamic range data or luminance values of individual pixels) and the program RADIANCE. As a means of testing their results from these techniques they used carefully monitored daylit test offices and subjective appraisals from 76 test subjects (the experiment was conducted at two different sites: the Danish Build Research Institute and the Fraunhofer Institute for Solar Energy Systems – 22 and 54 subjects respectively). Of this population, 48 were men, 28 female and 39 wore corrective lenses (however since the experiment was validating a glare prediction tool rather than assessing different user-group responses to glare, these differences between gender types and eye conditions were likely inconsequential).

Kasahara, et al. (2006) conducted an experiment into subjective appraisal of discomfort glare from LED light sources (as it is anticipated by the researchers that LED luminaires will become more widely used as the technology is developed). This experiment used 12 subjects, 11 of whom were male (although it is stated that two of the male subjects did not assess one of the luminance distributions in the experiment). No user-group types (gender, age etc) were analysed in the experiment. Kim, et al. (2007) conducted an experiment into the subjective appraisal of glare from daylight sources (windows). Using a similar technique to simulate a daylighting window than was used in the development of the DGI indices and this paper's experiment, they used 20 test subjects. There were an equal number of males and females used although gender effects were not examined (possibly because the sample sizes from each gender could be more or less representative of the actual population than the other).

The final study which was examined was an experiment by Sendrup (2001) attempting to validate a modification to the UGR formula making it more suitable for large area and indirect glare sources or sources below the line of sight. Two investigations were conducted, 30 subjects in the first run variation and 26 in the second (some modifications to the methodology were introduced in the second due to experience gained in the first run through). There was a "slight predominance of women" (p. 250) in each run through.

So with a sample size in this thesis' experiment of 48 subjects there is an acceptable statistical power given the typical variances in this type of study and this is also a stronger statistical power than a number of similar studies in subjective appraisals of discomfort glare. Possibly because of the variances in numbers of each gender or the sample sizes in those other experiments, they do not go so far as analysing user-group effects on subjective assessments. The statistical power would not be high and one user group may be more representative of the actual population than another if the number in each group varies. For this reason, the number from each gender is equal in this experiment although no conclusive findings regarding this or any other user-group is expected or assumed. The user-group analysis will only suggest possible avenues for further research based on hypotheses and apparent trends from this experiment and in no way suggests that the trends are representative of the total working age population who use VDUs in New Zealand.

2.2 Artificial Window & Simulated Office Design

This section outlines the equipment which was used in the calibration of the experiment and testing of subjects. The experiment was conducted within the confines of the Victoria University of Wellington's effulger (see images and description below). The artificial window used in the experiment was similar to the type of light-boxes used in the design of the daylight glare index (Hopkinson, 1972). Like that experiment, the artificial window in this experiment used 1500mm length daylight temperature (cool white 6500k), 58-watt fluorescent tubes to simulate a daylighting window (the fluorescent tubes used magnetic ballasts). The dimensions of the luminous part of the window measured 2400mm wide by approximately 1540mm high (to accommodate not only the fluorescent but the connectors and wire trays at the top edges). The light box was 300mm deep (allowing for adequate ventilation behind and in front of each of the lamps) with a distance between the lamps and the screen of approximately 250mm.

The interior of the box was painted with white ceiling paint to reflect as much light as possible out of the box and also help diffuse the light in order to make the luminance on the screen as seen from the outside of the artificial window as uniform as possible. The diffusing screen on the front of the artificial window was made from a 3.5mm thick white translucent acrylic sheet. It was thin enough to allow enough light through to the front of the window to create higher than recommended luminances (up to four times higher), but strong enough that it did not flex under either its own weight or from heat expansion/contraction during operation. The sheet was held on with small clamps around the outer edge of the window. Because the screen was larger than the void behind it (it was large enough to sit flush with the outer edges of the window frame), the clamps could hold the screen on without impacting on the luminous part of the screen allowing for a 3.6m^2 area of uniform, uninterrupted "daylight" window.

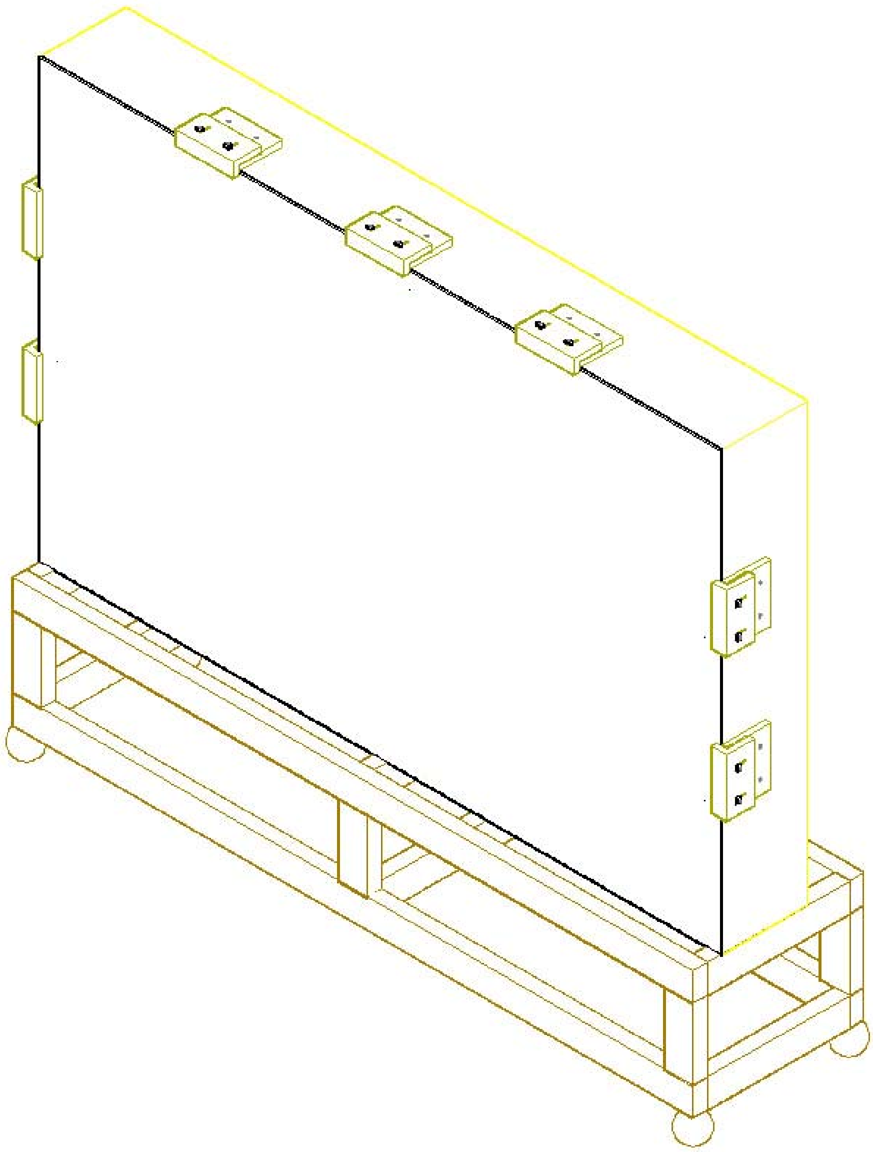
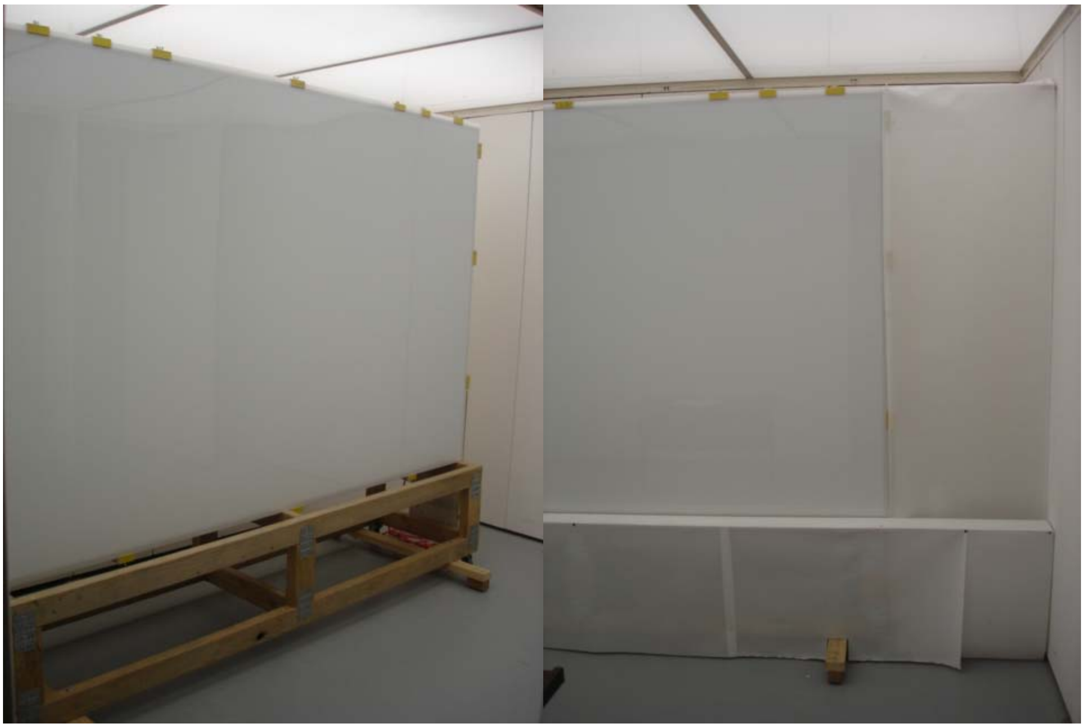


Figure 2.02 CAD image (AutoCAD) of artificial window

A window of this size was described as a '2' in the user survey (see section 2.7.3) and overall the average window size in the offices the user in this experiment worked in normally was very close to this figure suggesting the window was appropriately sized for the type of experiment being conducted. It was not so small it would not have a large impact on adaptation levels, nor so large that it was essentially a curtain wall (which logistically would be very difficult to achieve in the lighting laboratory at the school because of the height of the effulger where the experiment was conducted). The window was also comparable in size to similar studies (e.g. DGI see section 1.2.2).



Figures 2.03 – Figure 2.04 Photos of the artificial window used in the experiment with and without the additional curtain fabric covering the pedestal and sides

The artificial window was set on a moveable pedestal which allowed the window to sit 500mm above the ground. The front of the pedestal and areas beside the window were covered with a matte white curtain (see images 2.03 and 2.04). The top of the pedestal in front of and to the sides of the diffusing screen had a matte white “sill” (painted with the same ceiling paint used for the inside of the box). All of this was to create the impression of a daylighting window within a wall. The effulger itself was a square room with a width of 3495mm and height of 2300mm. The perimeter walls were white rotate-able panels and the ceiling (see image) was made up of warm white, dimmable fluorescent tubes behind a series of white translucent acrylic panels (similar to the artificial window itself). The walls of the effulger were covered with ceiling paint to render a matte white finish. It had a reflectance of approximately 0.8 based on the ratio of reflected to incident light on them. By surrounding windows with light coloured surfaces, the interior illuminance levels were higher and hence the contrast between the glare source and the surrounding surfaces was reduced. By reducing these contrasts, the risk of glare was reduced (Robbins, Claude 'Glare Analysis' Daylighting - D & A 1986). It was assumed that the use of matte white wall finishes was a reasonable representation of likely office environments as it fits in with the recommendations for surfaces surrounding daylight apertures.

Due to cost considerations, magnetic ballasts were used in the light-box so flicker from fluorescent tubes, although almost imperceptible by the human eye could potentially affect a person’s comfort without them truly being aware of it at the time. This could potentially impact on the results of the experiment so that the visual comfort assessments are not solely to do with the luminance ratios thereby reducing the accuracy of the results and hypothesis we are testing. These potential flicker effects were mitigated in the following ways:

- Firstly, the large number of fluorescent tubes inside the artificial window reduced the flicker effect. Even at the lowest luminance setting, there were seven fluorescent tubes on and these were all oscillating on and off at slightly different rates and times. The constructive and destructive interference of the light waves from multiple sources diffused the flicker effect.
- The second mitigating factor was the 3.5mm thick PERSPEX opal diffusing screen on the front of the light-box. After the light from the various fluorescent tubes has constructively/destructively interfered (it has a window width of 300mm with which to do this) it was then diffused further as it refracted as the light passed through the screen.

Aside from minimizing flicker, the number of tubes and diffusing screen also created a more uniform window luminance (where the areas in-between the tubes might otherwise cause noticeable brightness fluctuations although the edges of the window would have lower luminance values as they were a partial product of the reflectance of the wood panelling rather than the tubes themselves. However this variance was almost imperceptible to the human eye – see section 2.6 for numeric values for luminance variance on window screen).

2.3 Window Position and Simulated Office Layouts

Three different window positions were tested in this experiment:

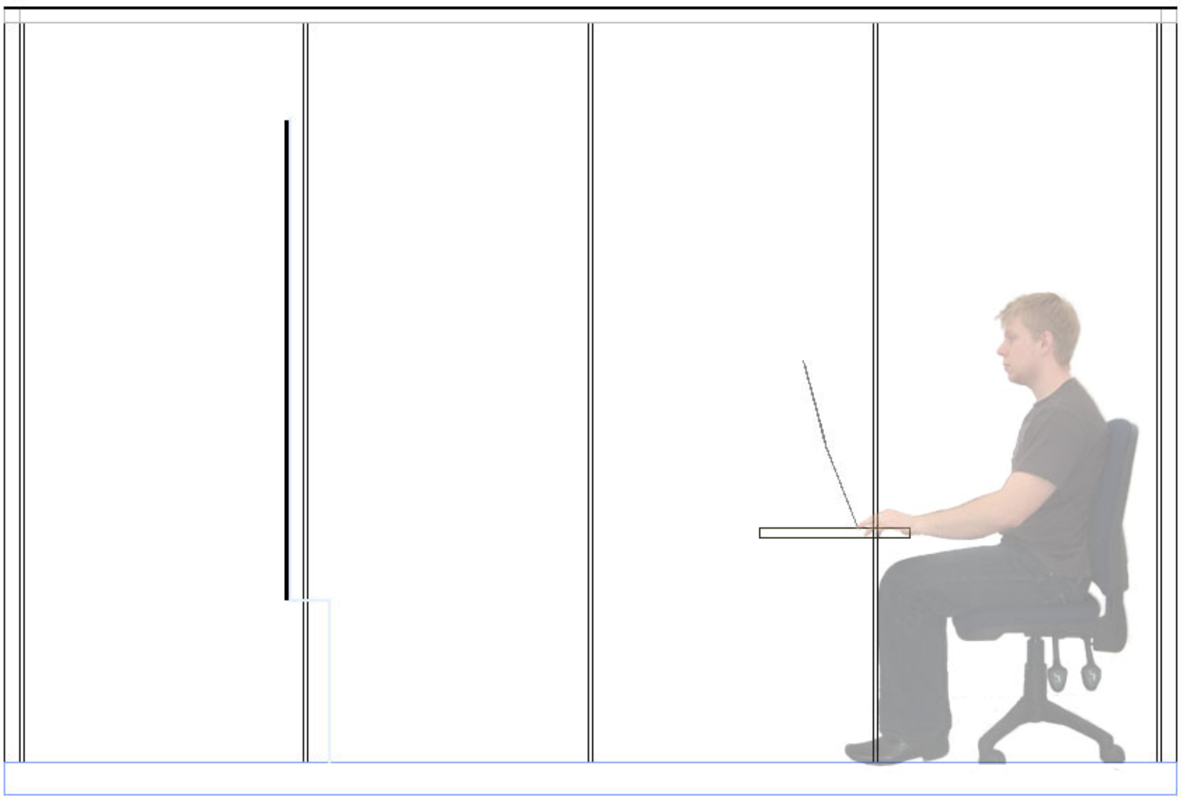


Figure 2.05 Side elevation of window front variation

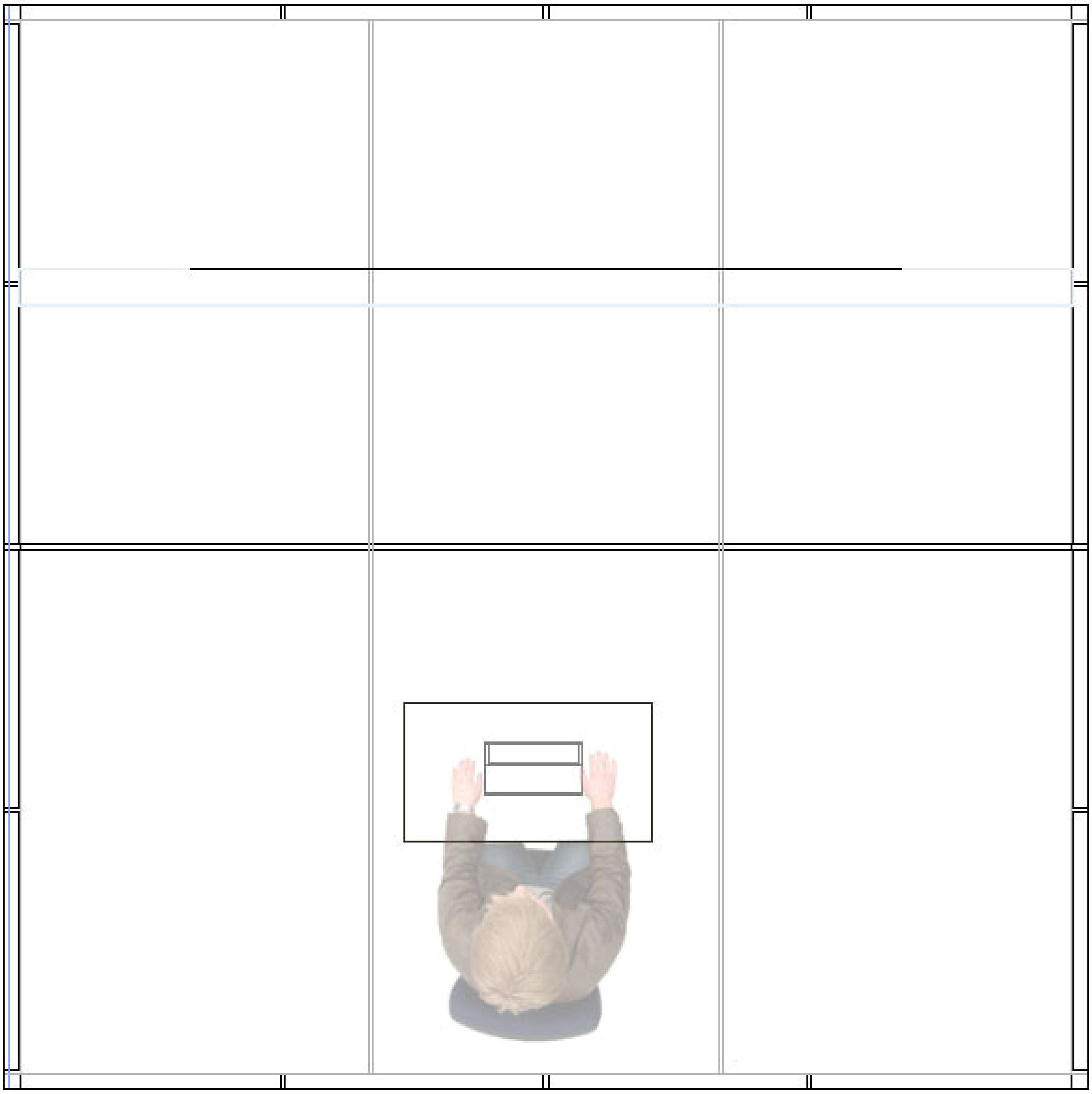


Figure 2.06 Plan view of window front variation

1. Window in front: This position was chosen as it would test users under conditions where there was a direct contrast between screen luminance in the foreground and the window luminance in the background. This position is not recommended by occupational safety and health (see images 2.09 and 2.10).

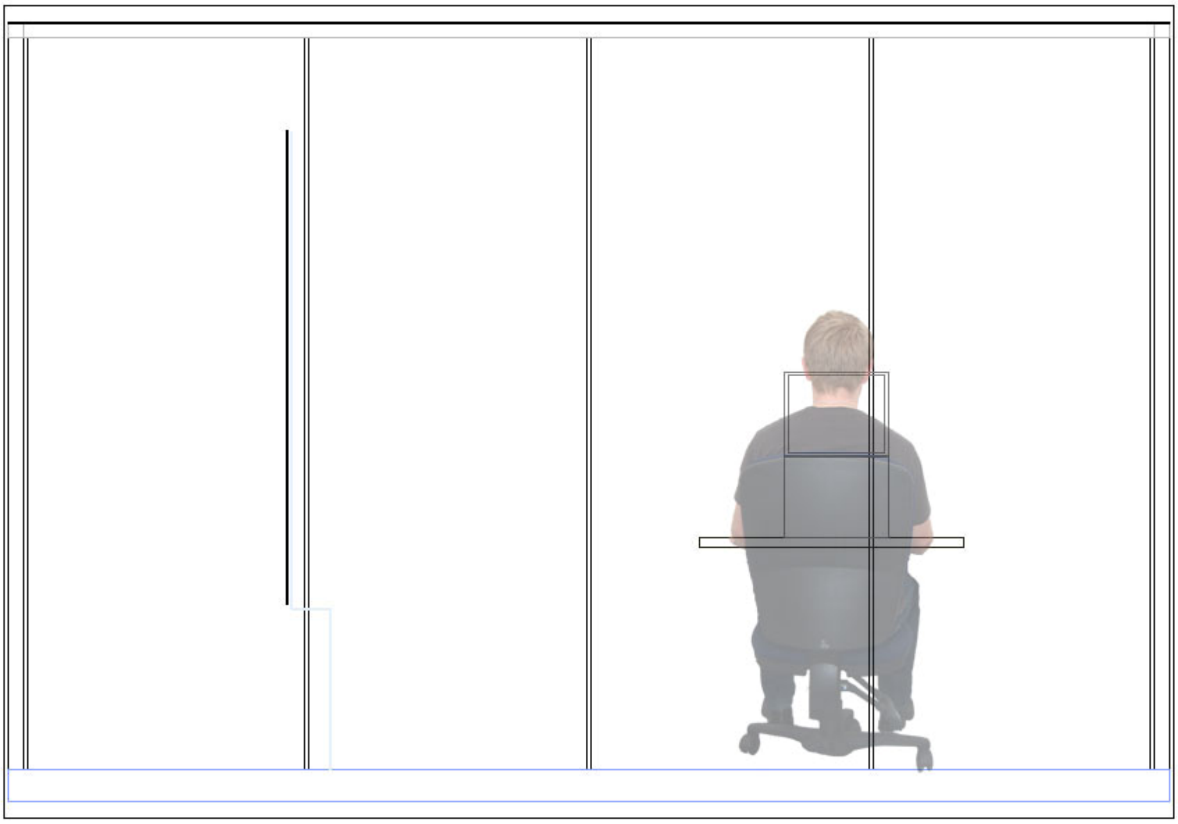


Figure 2.07 Side elevation of window left variation

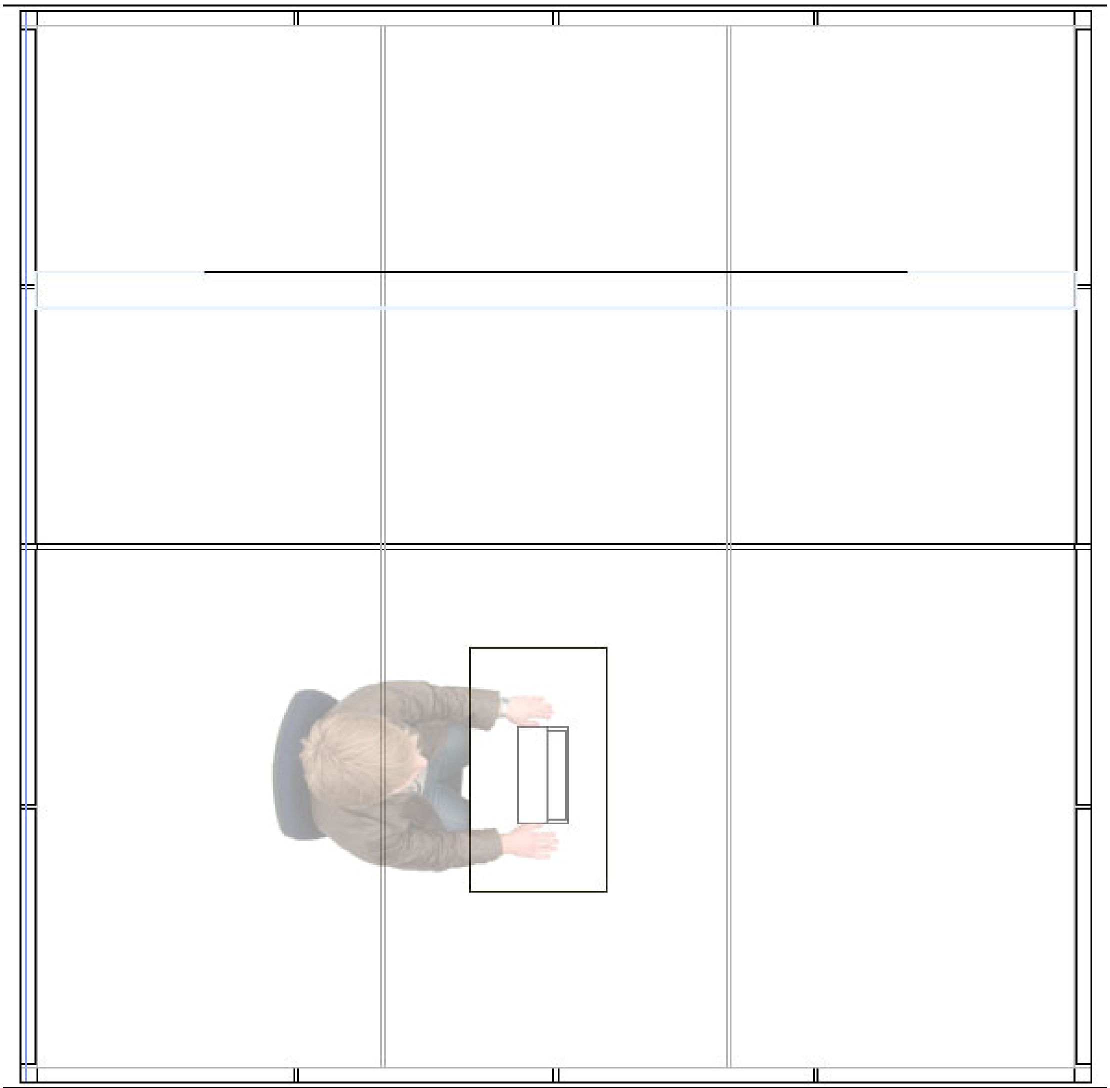


Figure 2.08 Plan view of window left variation

2. Window left: This position was chosen as an intermediate position between direct screen and window contrasts and veiling reflections. Many publications recommended workstations in daylit offices are placed perpendicular to any daylight sources (windows). This is because it still allows space users to enjoy the benefits of a daylit environment while having the window neither directly in the field of view nor casting veiling reflections directly onto the computer screen. Robbins (1986) actually recommended this position as the primary method to try and control glare in daylit spaces. Occupational Health and Safety Service (OSH) (1993) in New Zealand also recommended this and actually go as far as not recommending the other positions tested in this experiment (see images below) so analysing the subjective assessments and test performance of this position (window left variation) in relation to the other positions (window front and behind variations) could help confirm this recommendation as sound and provide a more tangible idea of the benefits to space users from using this layout.

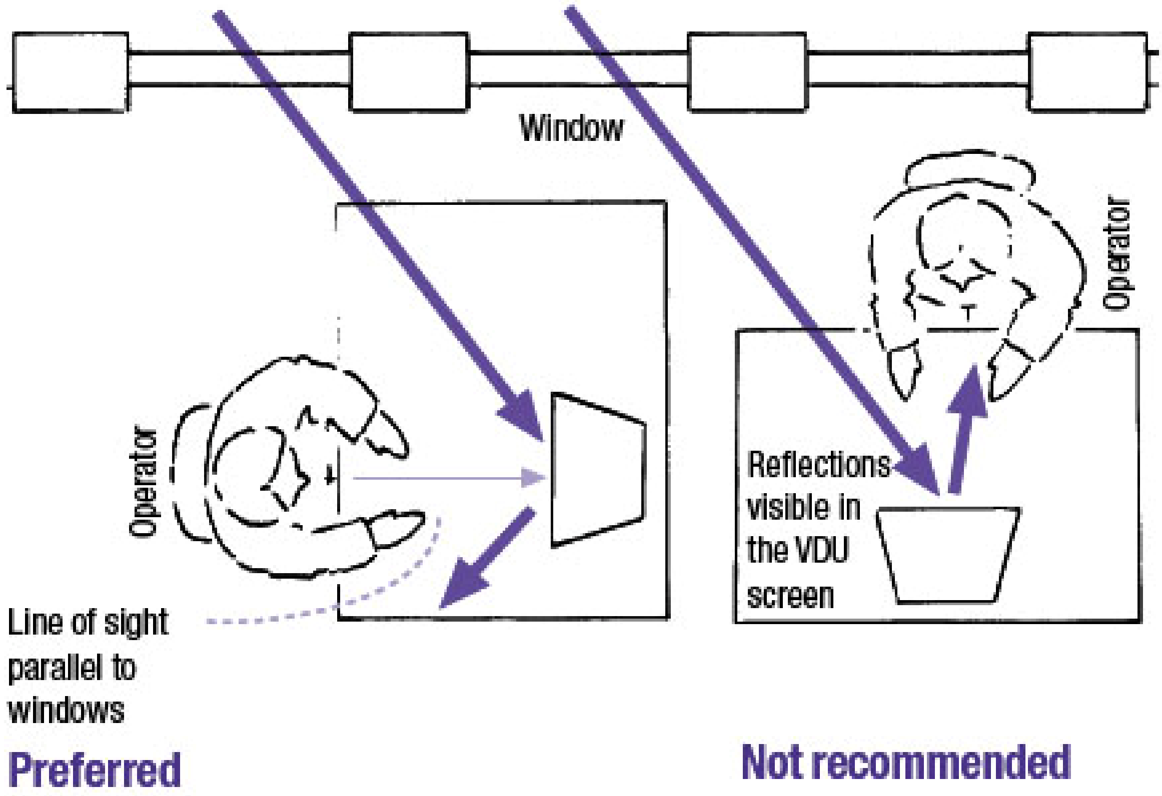


Figure 2.09 - Figure 2.10 OSH Illustration of recommended/not recommended workstation layouts

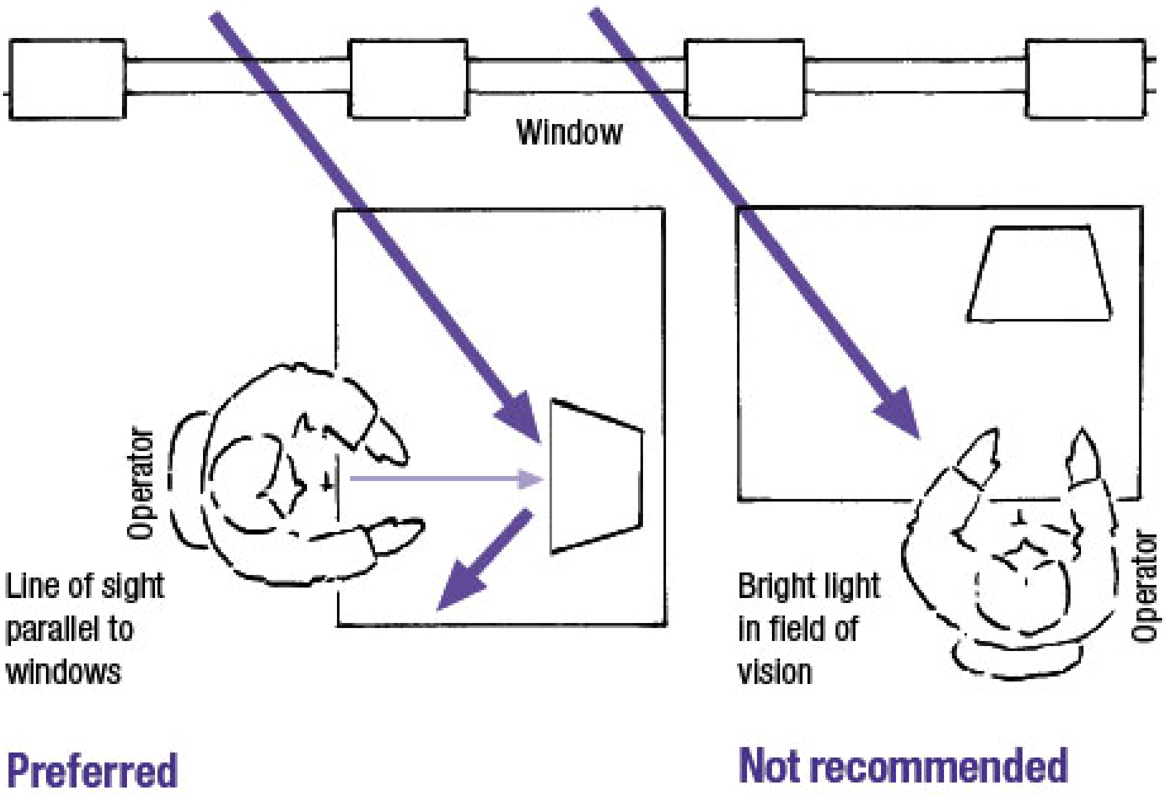


Figure 2.10

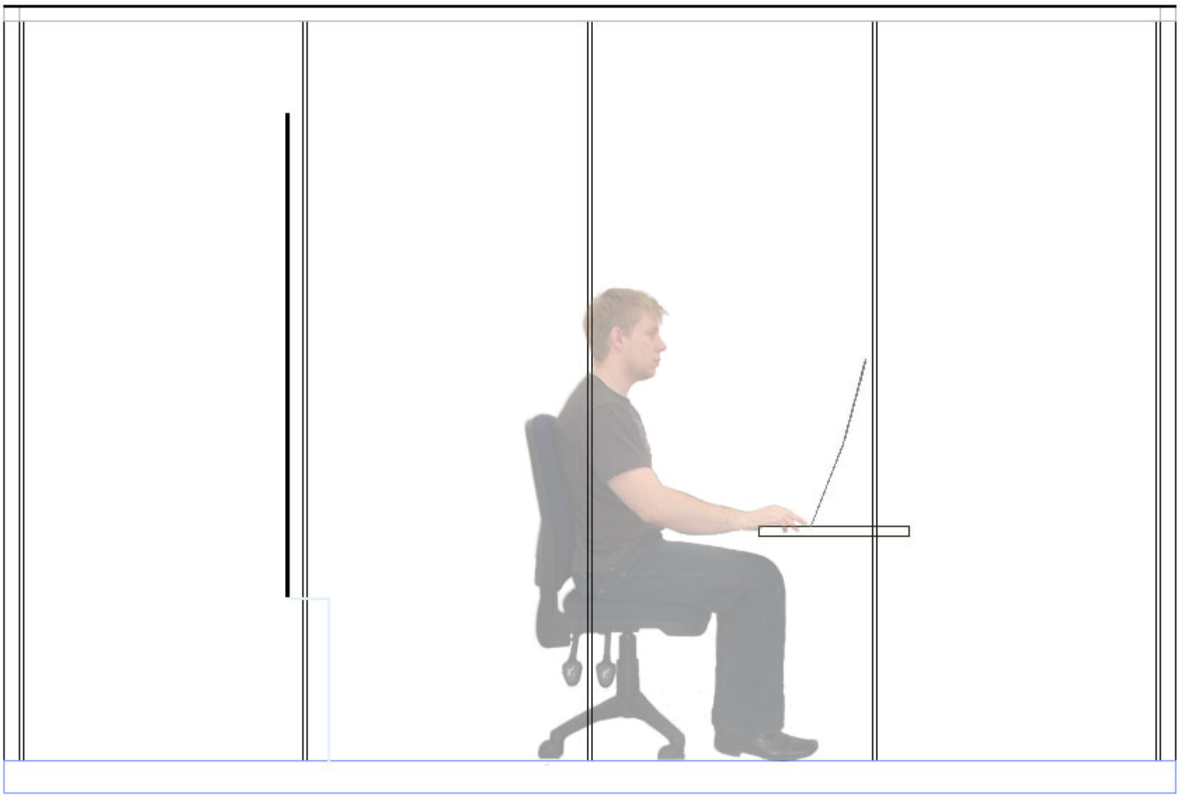


Figure 2.11 Elevation of window behind variation

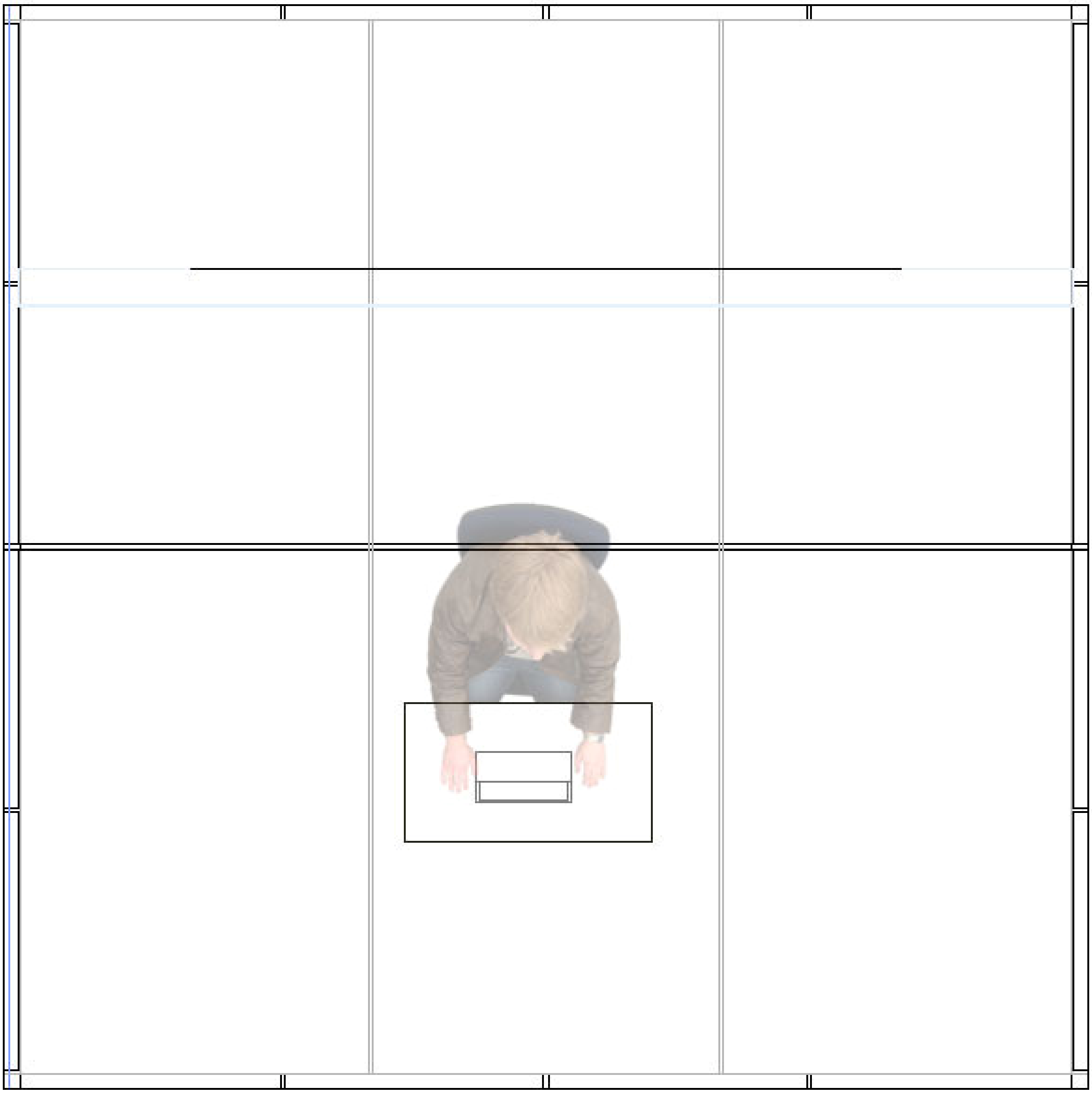


Figure 2.12 Plan view of window behind variation

3. Window behind: This position was chosen to cause veiling reflections which are commonly associated with 'disability glare' which reduces productivity and is caused by a reduction in contrast on the screen. Discomfort glare can also be associated with this position for that reason but also as the computer screen itself will reflect light back into the user's eyes. For these reasons it is not recommended by Occupational Health and Safety Service (OSH)(1993).

In terms of the specific user setup (the setup relating specifically to how the user was seated), the computer screen was tilted at 15° from the vertical to compensate for the natural inclination to tilt one's head towards the screen when working at a VDU. The height of the user was recorded (this is detailed in section 2.7.3) although the computer chair was adjustable to allow recommended OSH office setups to be observed and followed during the experiment (see image and description below) regardless of the actual height of any one subject and to ensure a reasonable consistency of eye position during the experiment. This experiment accepts that there will be some minor variations due to specific head tilt which was not controlled with a chin rest or like because of the desire to simulate a *realistic* VDU setup, which could reasonably be found in real-world office environs. The height of the chair was set such that the elbows and knees of the user were at an approximate 90° angle and the feet of the user were flat on the floor. The top of the computer screen was set at the same height as the horizontal line of sight of a hypothetical user (see below - relative to an un-tilted user head position) which created an approximate 10° angle between the top of the computer and the screen. In all cases the workstation was rotated about the centre the laptop screen so that the distance between the task area and the window would remain constant regardless of the users' specific head position.

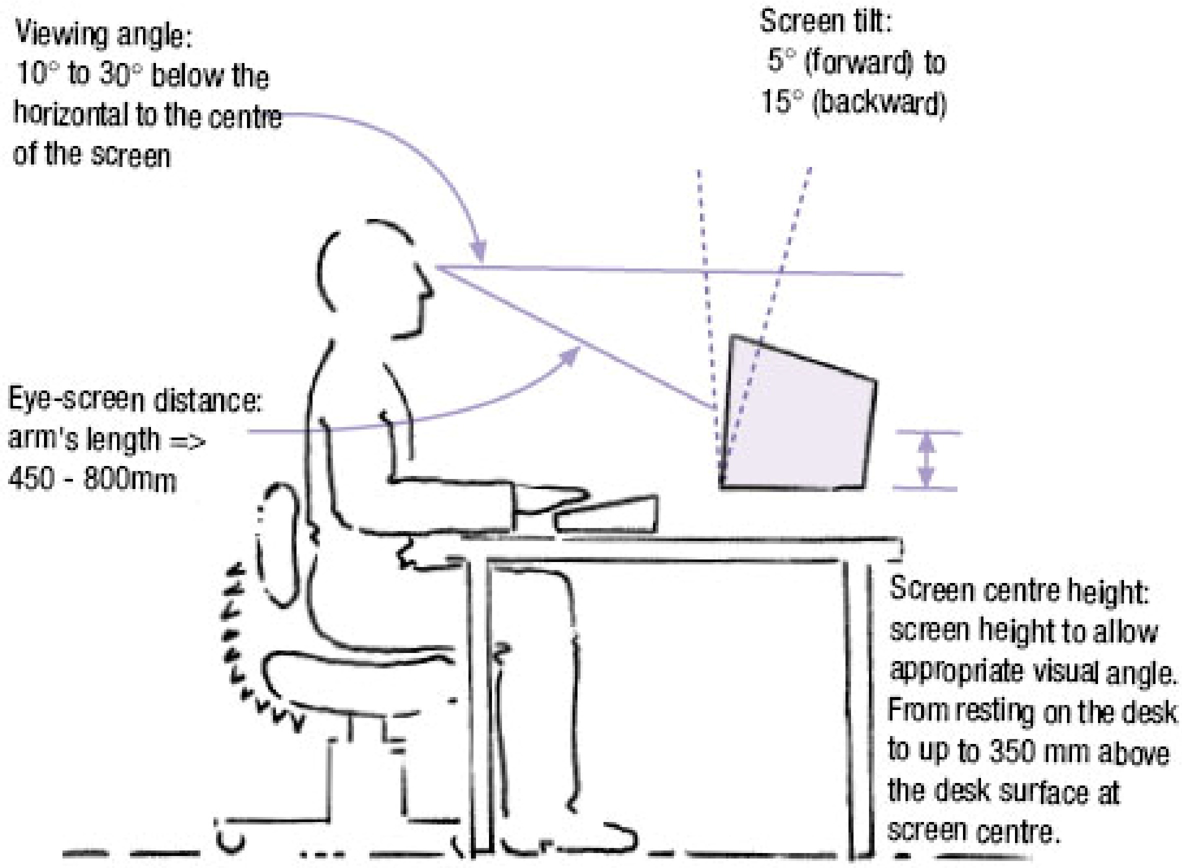


Figure 2.13 OSH recommended workstation setup (see figure list for image source)

2.4 Adaptation Levels and Field of View

According to the CIE, CIBSE and NZS1680, the recommended illumination levels for an office with an average level of computer based work and required accuracy is typically 300 – 500lux. At the start of every experiment the room was top lit using the Effulger's (see section 2.2) fluorescent tubes behind white opal diffusing screens (not dissimilar to the technique used in the artificial window) to the recommended illumination levels for an office. The user sat in the middle of the white room which resulted in an equal amount of light coming to the eye from each perimeter wall (this excludes whichever direction the window was in due to the position of the user in each test). The adaptation level of the eye was determined by measuring the vertical illumination at the eye with a 'Minolta T1 illuminance meter' (with the artificial window OFF) and putting this value into the formula (Wienold and Christoffersen, 2006):

Adaptation Luminance = Vertical Illumination at the eye / π

This was documented as the base adaptation level for the experiment. Between each test run (regardless of position or preceding window luminance) the test subject was exposed to this light level to allow the subject's eyes to adjust back to this base adaptation level. This was to reduce the effect of higher or lower adaptation levels of the eyes from a previous test run having an impact on the apparent brightness of the artificial window in the current test run which could influence either their visual test performance or subjective assessment of the quality of the lighting conditions.

The user field of view (or 'FOV') changes depending on the user position in each test (section 2.3). A general description of the field of view of each test position and the anticipated affect on adaptation levels of the eye is given below:

- Window in front: The user sits facing the computer with the artificial window directly in front of them. This is anticipated to cause the highest adaptation levels for the test subjects as the eyes will be directly facing the artificial window and therefore will have the highest vertical illumination. The FOV will consist mostly of the artificial window itself and a small portion being either the computer screen with the visual test or peripheral objects such as the walls and floor of the Effulger.
- Window left: The user sits at 90° clockwise from the artificial window (the window is on the test subject's left). The adaptation levels for this setup are expected to be lower than the previous setup. The majority of the FOV will be made up of the matt-white Effulger walls with the artificial window being visible in the peripheral field of view (left side). A small portion of the FOV will be made up of the computer screen and floor of the Effulger. Because much of the illuminance reaching the vertical plane of the test subject's eye will be reflected light from the walls and floor of the effulger, the adaptation

level is expected to be lower than the setup with the window in front of the subject.

- Window behind: The user sits at 180° from the artificial window (the window is behind the test subject). The adaptation levels for this setup are difficult to predict. The majority of the FOV is the matt-white walls of the Effulger with a small portion being taken up with the computer screen and floor which intuitively suggests that the illumination on the vertical plane of the test subject's eyes will be at a minimum. However, light from the artificial window can now shine directly onto some parts of the computer screen (this will vary depending on the size and shape of each test subject) and depending on the reflectance properties of the computer screen (see 1.1); some degree of light from the window may be reflected back into the test subject's eyes. This may make the adaptation level of the eyes in this setup more or less than the previous setup. It is unlikely that the adaptation levels would be higher than the first setup (artificial window in front) because the amount of light reaching the vertical illumination plane of the eye is a product of the material reflectance in the FOV and not light reaching the eye directly from the artificial window.

The adaptation luminances for each of the different window brightness and user position combinations are documented in section 2.5.

2.5 Vertical Illumination at the Eye

Many of the glare indices which exist for the prediction of the likelihood of discomfort glare perception rely on specifying the ratio between the luminance of the glare source and the average background luminance. The average background luminance is defined as the luminance of all the other surfaces in the FOV with the glare source removed. However, many modern indices are now incorporating a function '$\mathbf{E_v}$' which is defined as the vertical illuminance on the plane the user's eye is on. '$\mathbf{E_v}$' is a product of all the available light in the FOV which reaches the eye and therefore has a major impact on the adaptation levels of the eyes. By taking this value and inputting it into the adaptation luminance formula (see section 2.4) the background luminance value used in glare likelihood prediction indices now accounts for the impact of the glare source itself on the lighting levels in the space rather than assuming the glare source has no effect on this which we intuitively know not to be true.

"The human eye can see well within only a limited range of brightness at any given moment. The range rises and falls continually as we look around, its level being determined by the general level of brightness and specifically, by the brightest thing in view. This is a mechanism to avoid visual discomfort in daily life and to protect the sensors in the eyes from things that are troublesomely bright" (Bell and Burt, 1995, p. 4).

By considering this latter definition above as the principal background or 'adaptation' luminance rather than the former definition; the luminance ratios for visual comfort refer to the contrast between the luminance of the glare source and adaptation luminance or between the adaptation luminance and the task area luminance. By recording all of the possible definitions for recommended luminance ratios and looking at them in conjunction with recommended ratios for visual comfort, this thesis can also serve as a preliminary study into which definition of background luminance/task/glare source ratio shows the greatest correlation with overall user subjective assessments of visual comfort under each luminance distribution and office setup.

Luckiesh & Guth (1949) attempted to get around the issue of adaptation in the early luminance ratio experiments by keeping the exposure periods to a minimum. This was because the experimenters believed it was important to keep the adaptation during the exposure to the glare source as close to that of the base luminous conditions (without the glare source) as possible; the idea being that it would represent that sensation of glare brought about by an office worker looking briefly from their task area (which the eyes were adapted to) to a surface of higher brightness (quite possibly an accurate representation of conditions at the time of the experiment although modern office setups office can have large possibly even floor to ceiling curtain walls which are always within the field of view). These experiments would give subjects a series of 1 second duration exposures (which illustrates just how quickly the adaptation levels of the human eye can change) after which the subjects would give their subjective interpretation of comfort.

This thesis' experiment uses a visual test to allow time for test subjects to adapt to the new adaptation levels in the room caused by the window (which is naturally a more realistic simulation of actual modern office environs where users could be working anywhere up to eight hours under window lit conditions). Also, modern computers can have their screen luminance altered easily. By setting the luminance of the screen at a known level (see section 2.6), the task area luminance (the screen) alone can remain constant regardless of the impact the artificial window has on adaptation levels. This means the ratios being considered in this experiment are always relative to a known constant (window luminance:1 where the '1' is the constant screen luminance).

Following are the adaptation luminance levels for each of the different window positions and luminances (calculations can be found in appendix one & discussion/documentation of window luminances can be found in section 2.6).

Variation: Window in Front of User

Average Window Luminance	Vertical Illumination at eye	Adaptation Luminance
1567.35 cd/m^2	1349 lux	429.62 cd/m^2
3269.38 cd/m^2	2520 lux	802.55 cd/m^2
6332.65 cd/m^2	4390 lux	1398.1 cd/m^2

Table 2.1 Average window luminance, vertical illumination at the eye and adaptation luminance: Window front variation

Variation: Window Left 90° of User

Average Window Luminance	Vertical Illumination at eye	Adaptation Luminance
1567.35 cd/m^2	1025 lux	326.43 cd/m^2
3269.38 cd/m^2	1880 lux	598.73 cd/m^2
6332.65 cd/m^2	3100 lux	987.26 cd/m^2

Table 2.2 Average window luminance, vertical illumination at the eye and adaptation luminance: Window left variation

Variation: Window Behind User

Average Window Luminance	Vertical Illumination at eye	Adaptation Luminance
1567.35 cd/m^2	810 lux	257.96 cd/m^2
3269.38 cd/m^2	1370 lux	436.31 cd/m^2
6332.65 cd/m^2	2390 lux	761.15 cd/m^2

Table 2.3 Average window luminance, vertical illumination at the eye and adaptation luminance: Window behind variation

Variation: Window Off

Window Position	Vertical Illumination at eye	Adaptation Luminance
Front	223 lux	71.02 cd/m^2
Left	220 lux	70.06 cd/m^2
Behind	216 lux	68.79 cd/m^2

Table 2.4 Vertical illumination at the eye and adaptation luminance: Window off

In between each test run, the window was switched off to allow adaptation level of the users' eyes to adjust back to a base illumination level. Although there were some small variances in measured vertical illumination at the eye in each position (possibly due to the proximity of the eye to surfaces in the field of view such as the acrylic screen and effulger walls) the base illumination level in all the positions tested was essentially the same.

2.6 Window Luminance and Luminance Ratios

The luminances and luminance ratios used in the experiment were determined by measuring the luminance of the laptop screen, artificial window and surrounding surfaces (e.g. walls) using a 'Hagner Photometer'. The luminance of the laptop screen was set constant at a measured luminance of 100cd/m2 when the window was off (small variances in this figure were expected due to reflected light from the window itself and other surfaces when the window was in use).


Figure 2.14 – Figure 2.15 Photos of experiment calibration

The artificial window had three luminance settings which were used in this experiment and this depended on the number of tubes which were on inside the window (see images 2.17 – 2.19).
A number of different types of luminance ratios were considered in this experiment. Most recommendations for the promotion of visual comfort and productivity in offices refer to the ratios between task area luminance (which in the case of this experiment is the laptop screen), immediate and more distant surrounds. In the case of this experiment it is the ratio of computer screen luminance (which stays reasonably constant at 100cd/m2 although the light from the window will result in some fluctuations due to the reflectance and position of the screen and these were factored in ratio calculations), surfaces such as walls in close proximity to the task area (a table with dark colour and low reflectance was used to reduce ratios between the task area and the surface immediately adjacent) and the artificial window luminance. However, as some glare indices now incorporate an adaptation factor 'E' to account for the total amount of light reaching the eye (including light from the glare source as it is expected that this will have some effect on adaptation levels and therefore how disturbing a glare source of given luminance is), the ratio between the adaptation luminance, the task area and the artificial window luminance is also considered. The possibility exists that it is not the luminance ratios

that should be re-evaluated for a modern context but simply the definition of the factors included in the calculation of these ratios.

All of these ratios will be compared to recommended values along with the distribution of visual comfort responses to analyse which definition shows the best correlation between glare likelihood and recorded response levels. It is important to note than the ratios are documented such that the surface/light source with the higher luminance is on the left (e.g. Higher luminance: 1 where '1' is the luminance of the surface or light source with lower luminance). The window luminances (regardless of the particular setting the window was on) are displayed using the following false-colour scale (the unit is candelas per square meter cd/m^2). Some variance in the recorded window luminance was found, particularly at the highest settings. Contributing factors could be that some of the luminance values recorded were a product of largely direct light whilst others were a product of both direct and indirect light (reflected from the painted white interior). The photometer used to measure the luminances is also a sensitive enough piece of equipment to distinguish variations which are not perceptible to the human eye. Such was the case in this experiment where even at the highest window luminance setting, the recorded variations were not distinguishable by the human eye.

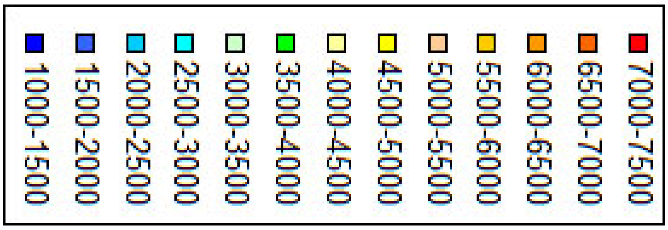


Figure 2.16 Colour scale used for luminance distributions of artificial window at each setting

Within Current Recommendations	
Borderline to Current Recommendations	
Exceeds Current Recommendations	

Table 2.5 Vertical illumination at the eye and adaptation luminance: Window off

Lowest Order Window Luminance (7 Tubes)

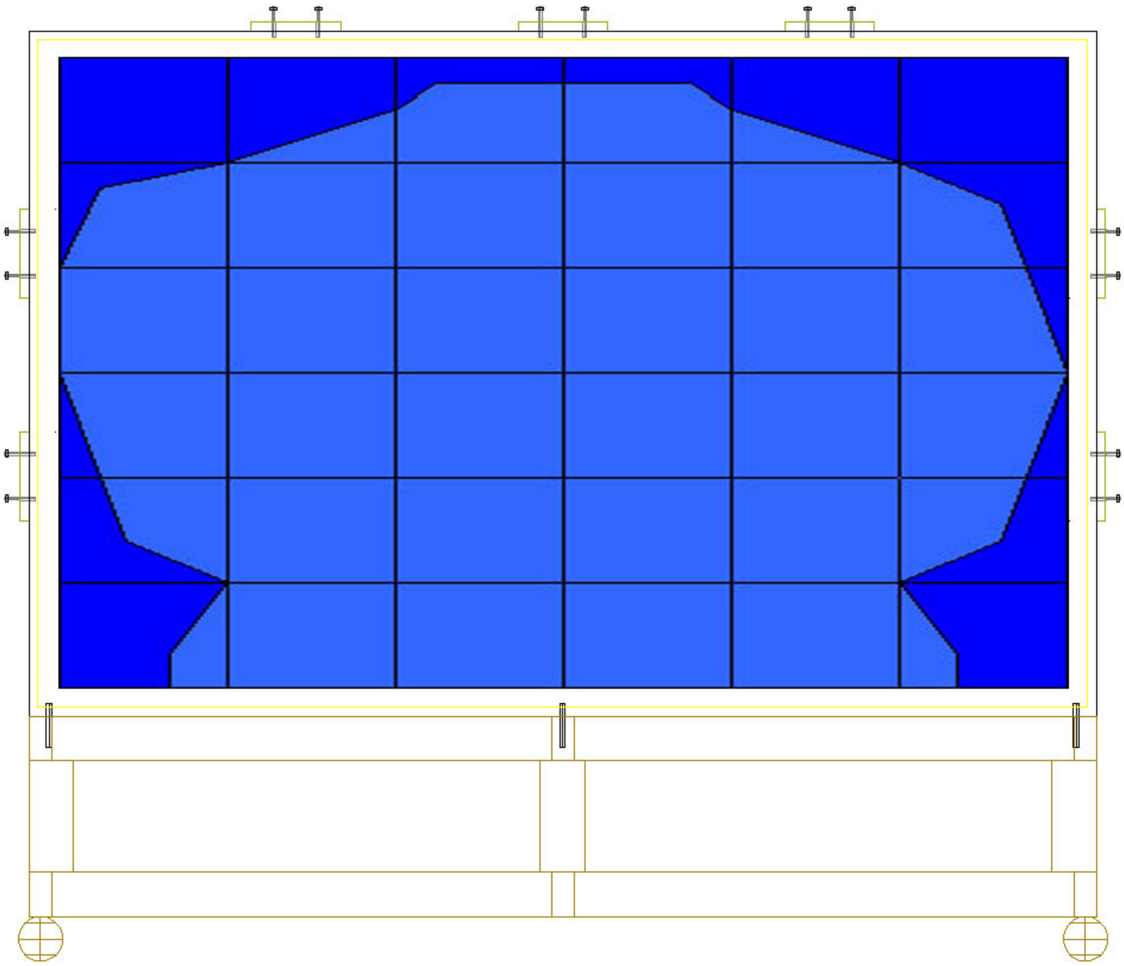


Figure 2.17 Luminance distribution of window at lowest luminance setting

Mean	Max	Min	S.D
1567.35 cd/m^2	1850 cd/m^2	1400 cd/m^2	137.14 cd/m^2

Table 2.6 Luminance mean, maximum, minimum and standard deviation: Lowest window setting

The average window luminance at the lowest setting is slightly above recommended maximum luminance for the field of view by 4.5%.

Luminance Ratios: Window Front Variation – Lowest Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	2.6 : 1
Artificial Window : Task (Laptop)	13.6 : 1
Adaptation Luminance : Task (Laptop)	3.7 : 1
Artificial Window : Adaptation Luminance	3.6 : 1
Artificial Window : Adjacent Surrounds (walls)	5.2 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	No

Table 2.7 Luminance ratios: Window front variation – Lowest setting

Most luminance ratios within the users' field of view are within recommended values although the 10:1 is exceeded between the immediate task area (the laptop screen) and the window source. It should be noted that this ratio does not take into account the potential effects of adaptation levels. If adaptation levels are important then subjective assessments for this permutation of window position and luminance should show a reasonable degree of visual comfort despite this ratio being exceeded. Also, as visual comfort is a product of both the luminance ratio *and* the luminance value itself and because this value is only marginally above the recommended threshold a high proportion of users below the border line of comfort and discomfort (BCD) is expected.

Luminance Ratios: Window Left Variation – Lowest Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	2.9 : 1
Artificial Window : Task (Laptop)	14.9 : 1
Adaptation Luminance : Task (Laptop)	3.1 : 1
Artificial Window : Adaptation Luminance	4.8 : 1
Artificial Window : Adjacent Surrounds (walls)	5.2 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	No

Table 2.8 Luminance ratios: Window left variation – Lowest setting

Moving the workstation into the recommended perpendicular-to-window position produces an interesting paradox. For reasons already discussed, it is anticipated to reduce the negative impact of daylighting on productivity and comfort. At the same time, less direct light from the window is reaching the vertical plane of the eye and the task plane (the laptop screen) which actually increases the ratio between these surfaces and the window (luminance stays constant). Most of the ratios are within recommended ranges although once again the immediate task to window luminance ratio exceeds 10:1. Despite this ratio being slightly higher when in the front position, the solid angle of the glare source (the window) is reduced, the window luminance is still only slightly above the recommended threshold, plus direct glare and veiling reflections have been reduced compared to the front variation. All of this suggests a high proportion of users will assess the conditions as below the BCD.

Luminance Ratios: Window Behind Variation – Lowest Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	2.0 : 1
Artificial Window : Task (Laptop)	10.4 : 1
Adaptation Luminance : Task (Laptop)	1.7 : 1
Artificial Window : Adaptation Luminance	6.1 : 1
Artificial Window : Adjacent Surrounds (walls)	5.2 : 1
Ratios outside recommended max of 10:1?	Borderline
Ratios outside recommended max of 40:1?	No

Table 2.9 Luminance ratios: Window behind variation – Lowest setting

Most of the ratios here are within recommended limits. The exception is the ratio between the task area and the window although in this position the ratio is only 4% above one of the recommended ratio limits. The reason for the reduction in this ratio is due to the increase in screen luminance resulting from direct light from the window washing over the screen itself. This is an example of the limitations of luminance ratio recommendations as despite the decrease, screen contrast will naturally reduce which could have ramifications in productivity (or possibly visual comfort). If a prediction of likely visual comfort levels was made from the information above only, it seems likely that most users would appraise the conditions well below the BCD. The impact of adaptation levels reducing the impact of already low luminance ratios reinforces this argument, as does the fact that the highest luminance ratio in this scenario does not actually occur *anywhere* in the field of view. The glare source in this layout is likely to be reflected luminances off the laptop screen which are well below the threshold for comfort (see section 1.1). Because we know the position of the window is behind the user, it is difficult to predict how comfort will be affected although it would be logical to expect that productivity will be noticeably hindered in this position (due to veiling reflections). At the same time the window luminance is still very close to recommended maximums suggesting the impact of the window may well be limited. Comparing the different positions' results may help quantify the impact of window position on productivity even if the luminance distribution at first suggests no likely problems.

Middle Order Window Luminance (15 Lamps)

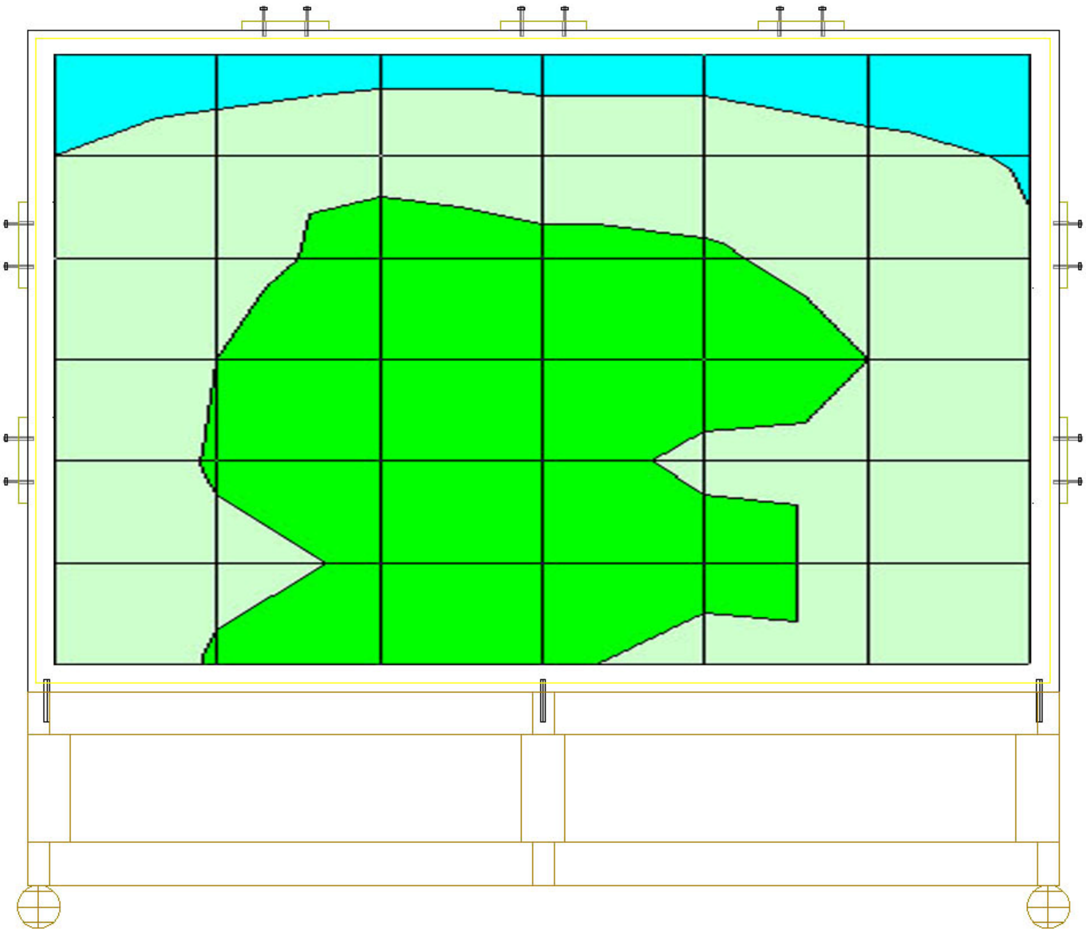


Figure 2.18 Luminance distribution of window at middle luminance setting

Mean	Max	Min	S.D
3269.38 cd/m^2	3850 cd/m^2	2500 cd/m^2	343.82 cd/m^2

Table 2.10 Luminance mean, maximum, minimum and standard deviation: Middle window setting

The average window luminance at the middle order setting is more than twice (118%) the recommended maximum. There is a potential that regardless of the ratios, the luminance of the window itself could cause visual discomfort or exclude the laptop luminance from the field of view.

Luminance Ratios: Window Front Variation – Middle Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	5.0 : 1
Artificial Window : Task (Laptop)	27.2 : 1
Adaptation Luminance : Task (Laptop)	6.7 : 1
Artificial Window : Adaptation Luminance	4.1 : 1
Artificial Window : Adjacent Surrounds (walls)	5.4 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	No

Table 2.11 Luminance ratios: Window front variation – Middle setting

Increasing the window luminance intuitively suggests an increase in the likelihood of glare and indeed if the recommended threshold holds true for daylit environments then this may well be the case. However at the same time the window luminance increases, overall illumination levels in the room will increase resulting in increase illumination of the vertical plane of the eye and subsequently, adaptation levels of the eye. For this reason the majority of the ratios themselves are comparable to those at the lowest window setting (although the luminance values involved will all be higher). The recurrent trend of task area/window ratio being in excess of the 10:1 limit continues although noticeably higher as the rate the laptops screen luminance increases (reflections from higher overall illumination levels) is much lower than the rate at which the window luminance increases.

Luminance Ratios: Window Left Variation – Middle Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	5.2 : 1
Artificial Window : Task (Laptop)	28.4 : 1
Adaptation Luminance : Task (Laptop)	5.2 : 1
Artificial Window : Adaptation Luminance	5.5 : 1
Artificial Window : Adjacent Surrounds (walls)	5.4 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	No

Table 2.12 Luminance ratios: Window left variation – Middle setting

Having the window perpendicular to the work station causes a lower screen luminance than the front variation which increases the ratio between the laptop screen and the window despite being in the recommended positions. In this experiment the lower screen luminance was assumed to be due to the fact that in the front variation the workstation was closer to the white walls of the effulger so more reflected lighting from the walls was able to then reflect off the laptop screen. Aside from this ratio, all the others are within recommended limits. Again it is difficult to predict the overall level of visual comfort for this permutation. This is because the workstation is in the recommended position, but the window luminance and one of the ratios is above some of the recommended limits for visual comfort.

Luminance Ratios: Window Behind Variation – Middle Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	3.0 : 1
Artificial Window : Task (Laptop)	16.3 : 1
Adaptation Luminance : Task (Laptop)	2.2 : 1
Artificial Window : Adaptation Luminance	7.5 : 1
Artificial Window : Adjacent Surrounds (walls)	5.4 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	No

Table 2.13 Luminance ratios: Window behind variation – Middle setting

Positioning the workstation with the window directly behind the user is a doubled edged sword. On the one hand it results in direct light from the window reaching the plane of the laptop screen creating a higher screen luminance and reducing the ratio between it and window. On the other hand this ratio is nowhere in the field of view (possibly making it inconsequential), adaptation levels of the users' eyes are lower, window luminance is above recommended comfort thresholds and the screen contrast is reduced suggesting at the very least a substantial decrease in productivity although the impact on visual comfort is difficult to predict. This is because the other ratios are all within recommended limits although the adaptation to window luminance ratio is higher than in other positions due to the decrease in light reaching the vertical plane of the eye. On the other hand the adaptation to task area luminance ratio which is arguably the most applicable (as the window itself is not in the users' field of view) in this situation is lower than the other positions.

Highest Order Window Luminance (30 Lamps)

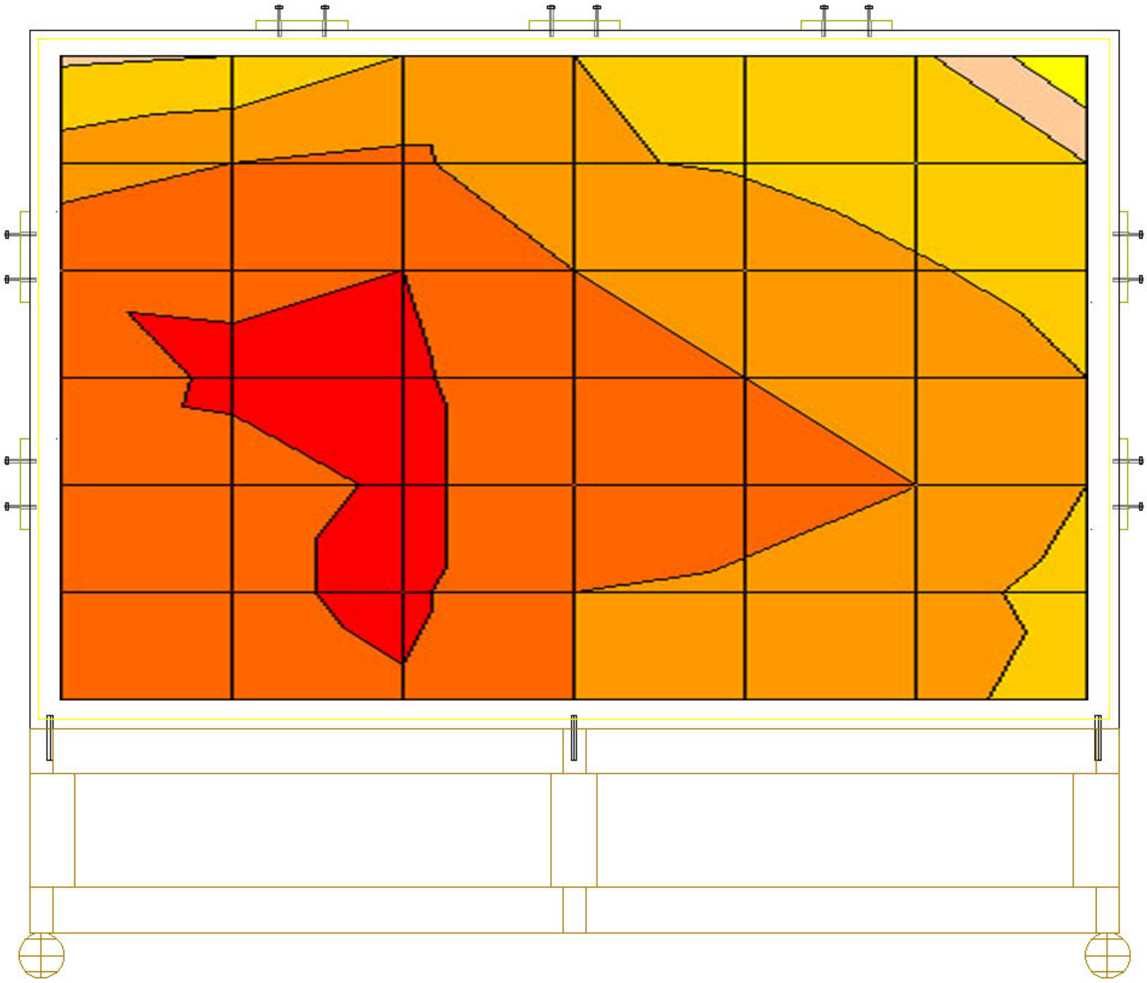


Figure 2.19 Luminance distribution of window at highest luminance setting

Mean	Max	Min	S.D
6332.65 cd/m^2	7150 cd/m^2	4500 cd/m^2	554.12 cd/m^2

Table 2.14 Luminance mean, maximum, minimum and standard deviation: Highest window setting

In the highest order window brightness variations, the average window luminance was more than four times (322%) the recommended limit. It would seem likely that regardless of the window position (with the possible exception of the 'window behind the user' variations where it is not in the field of view) visual comfort will be greatly impaired at this setting.

Luminance Ratios: Window Front Variation – Highest Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	7.4 : 1
Artificial Window : Task (Laptop)	46.9 : 1
Adaptation Luminance : Task (Laptop)	10.4 : 1
Artificial Window : Adaptation Luminance	4.5 : 1
Artificial Window : Adjacent Surrounds (walls)	6.3 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	Yes

Table 2.15 Luminance ratios: Window front variation – Highest setting

This is the first time the luminance distribution causes ratios in excess of the higher possible limit (40:1). As we have observed in all of the previous variations, this is predictably the ratio between the task area and window luminance. However in this scenario because the user is facing the window directly, and the window has a high luminance, the light reaching the vertical plane of the users' eyes and hence the adaptation levels of them are also sufficiently high to cause a borderline comfort ratio between the adaptation and task luminance. If adaptation truly is an important factor in visual comfort assessment from luminance ratios then overall visual comfort appraisal for this variation should see a large proportion of users above the BCD. The rest of the luminance ratios are within recommended limits and in some circumstances actually lower than lower window luminance variations due to the relative increases in surface/light source luminance between window brightness settings.

Luminance Ratios: Window Left Variation – Highest Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	8.0 : 1
Artificial Window : Task (Laptop)	50.7 : 1
Adaptation Luminance : Task (Laptop)	7.9 : 1
Artificial Window : Adaptation Luminance	6.4 : 1
Artificial Window : Adjacent Surrounds (walls)	6.3 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	Yes

Table 2.16 Luminance ratios: Window left variation – Highest setting

With the window perpendicular to the workstation, the relative decrease between adaptation luminance and screen luminance is such that the ratio between the two is once again below recommended limits and the ratio between the window and the task is once again the only ratio to breach the threshold. Despite most of the ratios being within recommended limits, the fact that the window luminance itself is outside the recommended maximum and the ratio between window and task luminance is outside both possible limit types suggests that few users will assess visual comfort below the BCD despite the window being 90° from the centre of the users' field of view.

Luminance Ratios: Window Behind Variation – Highest Luminance Setting

Definition (surfaces in ratio)	Ratio
Adjacent Surrounds (walls) : Task (Laptop)	3.3 : 1
Artificial Window : Task (Laptop)	21.1 : 1
Adaptation Luminance : Task (Laptop)	2.5 : 1
Artificial Window : Adaptation Luminance	8.3 : 1
Artificial Window : Adjacent Surrounds (walls)	6.3 : 1
Ratios outside recommended max of 10:1?	Yes
Ratios outside recommended max of 40:1?	No

Table 2.17 Luminance ratios: Window behind variation – Highest setting

Finally and predictably, most ratios in this variation are within the recommended limits with the exception of the ratio between the task and the window luminance. It is important to note that this ratio is not anywhere within the users' field of view although the reflections off the laptop screen would be most severe in this variation. Again the ratio which is most applicable due to the fact that the window/task ratio reflects values outside the field of view is likely to be the adaptation to task luminance ratio. This ratio is well within recommended limits due to the fact that adaptation luminance is low (as no direct light from the window reaches the vertical plane of the users' eyes) and the screen luminance is high due to receiving direct light from the window. However, a large reduction in screen contrast is likely so productivity will probably suffer worst in this variation in comparison to all others in the experiment. It is difficult to predict likely visual comfort levels due to the low ratios but high window luminance and likely low screen contrasts.

2.7 Experiment Methodology

Offices are typically an integration of both electrical and natural light sources. A similar study with artificial light source studies (Linney, 2005) suggested luminance ratios far in excess of currently recommended values could be acceptable under certain conditions. In those tests the solid angle was much smaller than the solid angle of the glare source in this thesis' experiment and as such the overall illumination levels and adaptation levels of the eye were much lower so the result may not be applicable to daylit offices or only to offices without windows or at night. Simulating and experimenting with daylit environments on top of this would provide a more accurate representation of actual office environments. Humans can cope with reasonably high luminance levels so long as the adaptation level of the eyes is sufficiently high. A typically and appropriately sized day-lighting window (similar in dimensions to artificial windows used in previous studies) tends to set the adaptation levels because it has such a large effect on the overall lighting levels within a space.

1. Using a similar technique to simulate a diffuse day-lighting window (see section 1.2.2) to that which was used to design the 'Daylight Glare Index' (DGI), a range of lighting layouts were simulated (using ceiling mounted fluorescent lamps and a day-lighting window to represent typical office lighting conditions). The layouts include different window orientations (e.g. in front of, peripherally located and behind the user for veiling reflections).
2. Users were asked to perform a simple word and visual test under each lighting layout (which could later be used to correlate subjective assessment with performance) as an objective measure of the quality of each luminance distribution. For the purposes of this research, 'productivity' has been defined in two ways:
   a) number of errors;
   b) test duration.
3. At the conclusion of each particular run (lighting layout), subjects were asked to subjectively assess how they felt about the conditions on a continuum as in the following section (see section 2.7.2 - figure 2.23).

2.7.1 Objective Assessment (Visual Tests)

As an objective measure of the quality of the various luminous distributions which were presented to test subjects in this experiment, a visual test was used. The visual test was on a series of PowerPoint slides. The visual test did not require any prior knowledge of how to use PowerPoint or for subjects to demonstrate ability to type or use a mouse (which could vary between subjects depending on their level of experience with a computer or Microsoft office software). This was an attempt to make the intrinsic difficulty of each individual visual test performed during the experiment as equal to each other as possible. Test performance for the Landolt ring sections were measured in two main ways:

- Test duration
- Test errors

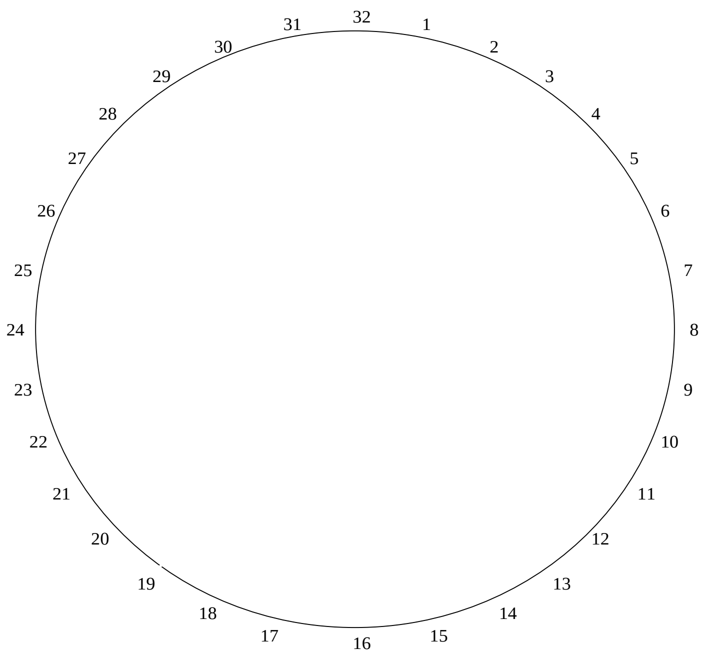


Figure 2.20 Example of Landolt ring variation used in this experiment's visual test

Each visual test consisted of 33 slides (see figures 2.20 and 2.22). Slides 1 – 16 and 18 – 32 were a variation of 'Landolt rings' which are used to measure visual acuity under different light sources and illumination levels.

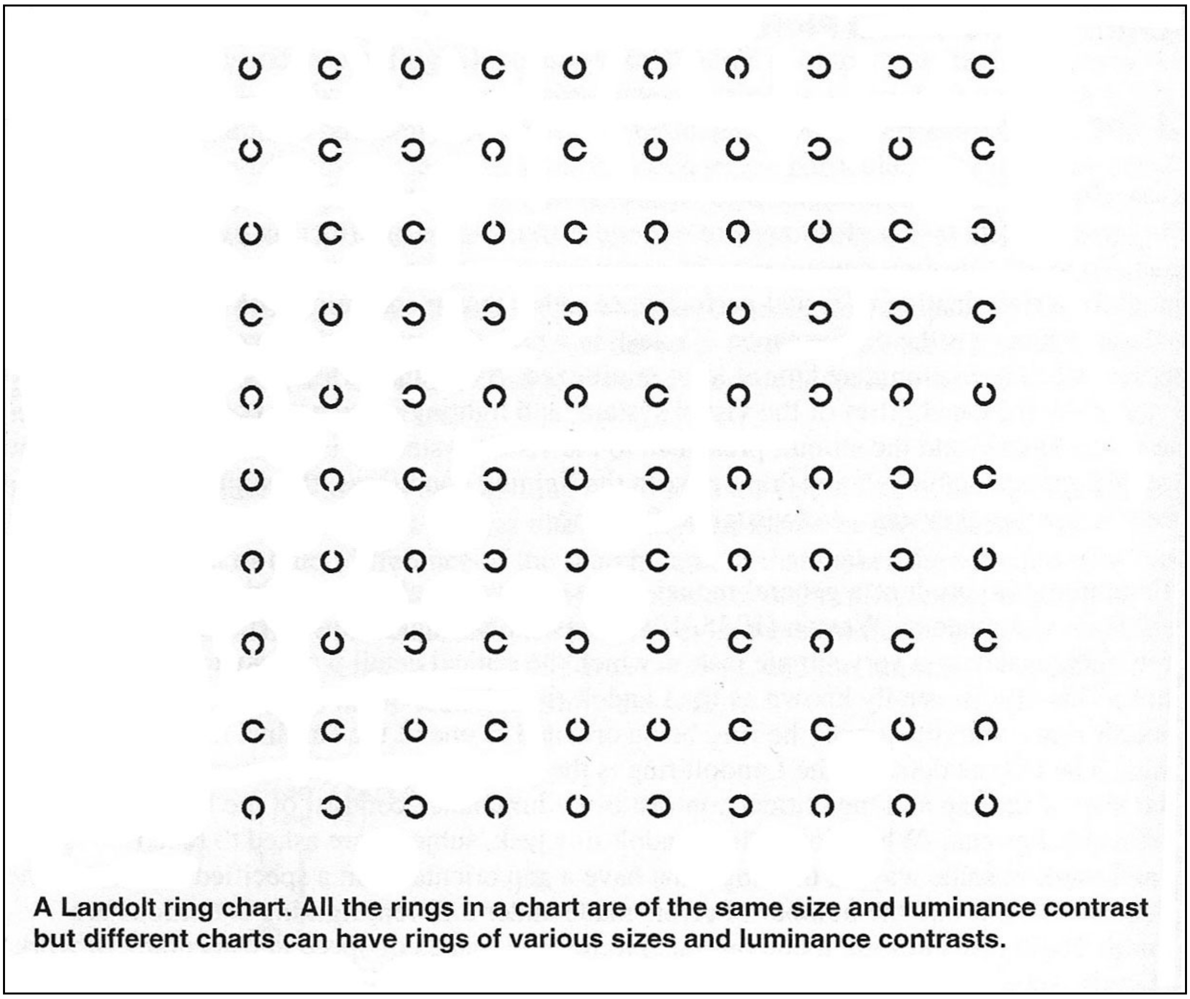


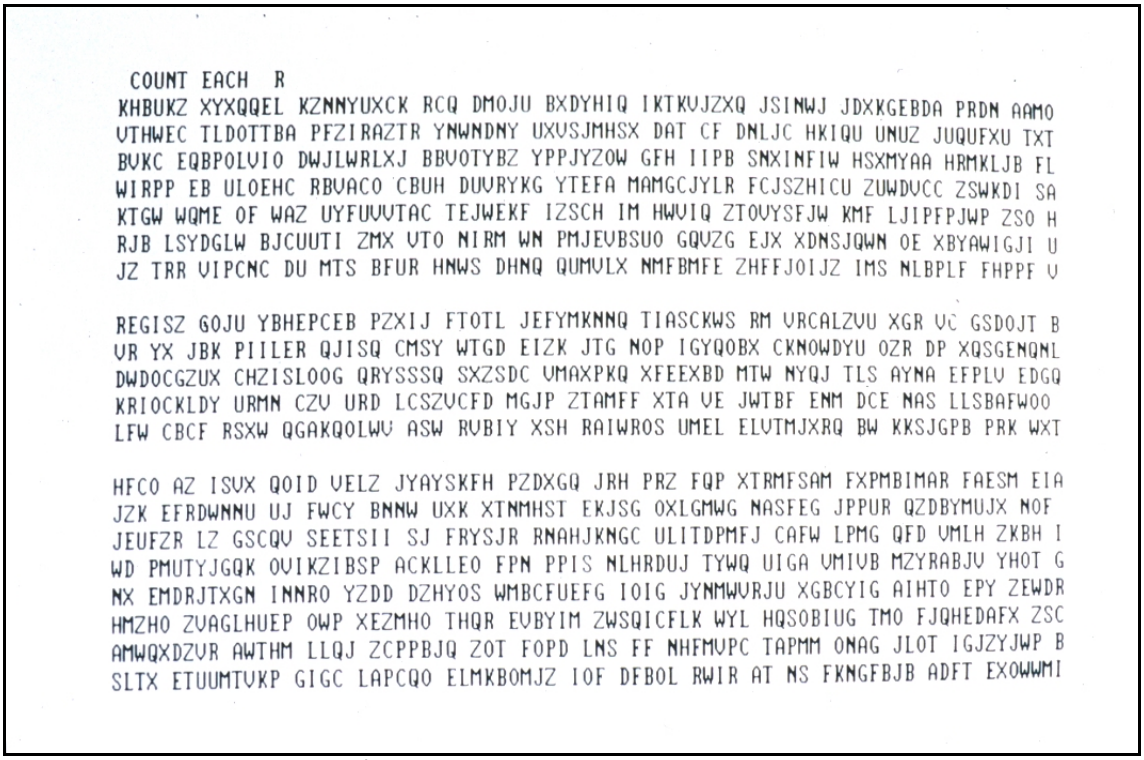
Figure 2.21 Example of traditional Landolt ring chart used in visual acuity tests

While the underlying principal of the Landolt ring was still present in this experiment, some variations on the original concept were made. Traditionally test subjects were presented with a sheet of paper which contained Landolt rings of small size (see figure 2.21). The test subjects would then use a pen to go across the page and mark where a small slit had been cut out of the edge of each of the rings. This experiment uses the same concept of locating a slit around the end of each ring but the following changes were made to make the test conducive to a computer based setup and render the subjects ability to quickly mark slits in the ring's edge using a pen unnecessary:

- Only one large ring was used on each slide rather than many small rings and the line weight was reduced. This was to encourage test subjects to have to scan a larger area of the computer screen and reduce the effect of the slits on the rings above/below the horizon or left/right of the screens centre being intrinsically easier to find.
- In order to demonstrate that the test subject had scanned the ring and comprehended exactly where on the ring's edge the slit was, the ring had the numbers 1 – 32 spaced evenly around the ring's edge and test subjects simply read out aloud the number which corresponded with that section of the ring's edge (see figure 2.20).

- Each slide with a ring on it was timed. Test subjects had four seconds to search for the slit and read out the corresponding number (this time limit was decided upon prior to commencement of the experiment by recording the average time for test runs of the visual test where the subjects were under glare-free conditions – see Linney, 2005). If, during the experiment a test subject could not locate the slit and read out the corresponding number from the ring's edge within the allotted time limit then this was recorded as an error on the answer sheet and PowerPoint would simply move onto the next ring automatically. If a subject found the slit and called out the corresponding number within the time limit they could either wait for the slide show to automatically move onto the next slide for them or they could click the right mouse-button and the next slide was manually brought up for another four seconds.

Subjects had it made clear to them prior to the commencement of the experiment that the purpose of the visual test was to try and be as efficient as possible with regards to time and errors. For some types of test subjects this could possibly mean as fast as possible and for others it could possibly mean as accurately as possible. This is why both visual test duration and visual test errors were recorded and why overall test performance is a product of both of these factors.


COUNT EACH R
KHBUKZ XYXQQEL KZNNYUXCK RCQ DMOJU BXDYHIQ IKTKUJZXQ JSINWJ JDXKGEBDA PRDN AAMO
VTHWEC TLDOTTBA PFZIRAZTR YNWNDNY UXUSJMHSX DAT CF DNLJC HKIQU UNUZ JUQUFXU TXT
BVKC EQBPOLVIO DWJLWRLXJ BBVOTYBZ YPPJYZOW GFH IIPB SNXINFIW HSXMYAA HRMKLJB FL
WIRPP EB ULOEHC RBVACO CBUH DUVRYKG YTEFA MAMGCJYLR FCJSZHICU ZUWDVCC ZSWKDI SA
KTGW WQME OF WAZ UYFUVVTAC TEJWEKF IZSCH IM HWVIQ ZTOVYSFJW KMF LJIPFPJWP ZSO H
RJB LSYDGLW BJCUUTI ZMX VTO NIRM WN PMJEVBSUO GQVZG EJX XDNSJQWN OE XBYAWIGJI U
JZ TRR VIPCNC DU MTS BFUR HNWS DHNQ QUMVLX NMFBMFE ZHFFJOIJZ IMS NLBPLF FHPPF V

REGISZ GOJU YBHEPCEB PZXIJ FTOTL JEFYMKNNQ TIASCKWS RM VRCALZVU XGR VC GSDOJT B
VR YX JBK PIILER QJISQ CMSY WTGD EIZK JTG NOP IGYQOBX CKNOWDYU OZR DP XQSGENQNL
DWDOCGZUX CHZISLOOG QRYSSSQ SXZSDC VMAXPKQ XFEEXBD MTW NYQJ TLS AYNA EFPLV EDGQ
KRIOCKLDY URMN CZV URD LCSZVCFD MGJP ZTAMFF XTA VE JWTBF ENM DCE NAS LLSBAFWOO
LFW CBCF RSXW QGAKQOLWV ASW RVBIY XSH RAIWROS UMEL ELVTMJXRQ BW KKSJGPB PRK WXT

HFCO AZ ISVX QOID VELZ JYAYSKFH PZDXGQ JRH PRZ FQP XTRMFSAM FXPMBIMAR FAESM EIA
JZK EFRDWNNU UJ FWCY BNNW UXK XTNMHST EKJSG OXLGMWG NASFEG JPPUR QZDBYMUJX NOF
JEUFZR LZ GSCQV SEETSII SJ FRYSJR RNAHJKNGC ULITDPMFJ CAFW LPMG QFD VMLH ZKBH I
WD PMUTYJGQK OVIKZIBSP ACKLLEO FPN PPIS NLHRDUJ TYWQ UIGA VMIVB MZYRABJV YHOT G
NX EMDRJTXGN INNRO YZDD DZHYOS WMBCFUEFG IOIG JYNMWVRJU XGBCYIG AIHTO EPY ZEWDR
HMZHO ZVAGLHUEP OWP XEZMHO THQR EVBYIM ZWSQICFLK WYL HQSOBIUG TMO FJQHEDAFX ZSC
AMWQXDZVR AWTHM LLQJ ZCPPBJQ ZOT FOPD LNS FF NHFMVPC TAPMM ONAG JLOT IGJZYJWP B
SLTX ETUUMTVKP GIGC LAPCQO ELMKBOMJZ IOF DFBOL RWIR AT NS FKNGFBJB ADFT EXOWWMI

Figure 2.22 Example of letter counting test similar to the ones used in this experiment

The 17th slide was different to the Landolt ring slides. It had no time limit (unlike the rings portion of the visual test), served to segment the visual test up and also have test subjects perform more than the one simple visual task during the course of the experiment. Test performance for the 'letter count' section was measured in two main ways:

- Test duration
- Standard deviation from correct answer

This part of the visual test was used in a similar experiment (Osterhaus et al, 1992) using an artificial window to study the impact of various daylight luminance distributions on visual acuity. The slide contained three paragraphs of nonsensical words which were derived from a random letter generator (The tests were originally a 5 line by 80 character paragraph – see figure 2.22). At the top of these 'letter-count' slides was a title which asked test subjects to count the number of times a specific letter appeared in the middle of the three paragraphs. The following conditions were set to ensure that again the intrinsic difficulty of the letter counting portion of the visual tests was as equal as feasibly possible across all of the visual tests.

- This slide had no time limit. Individuals reading comprehension levels would potentially hinder certain test subjects ability to count the number of letters specified in any allotted time limit.
- The letters which were specified for subjects to search for were chosen based on how difficult it could potentially be to mistake them for other letters. In the original experiment the letters 'N', 'R' and 'W' were chosen. The 'N' and 'W' were chosen for their similarities to not only each other but the letters 'V' and 'M'. The 'R' was chosen for its similarities to both 'K' and 'P'.
- The paragraphs' lengths were all set to be of approximately the same length/area of text, so that the amount of time it would take to scan with the eyes through it would not vary to any great degree from that factor alone. This was so that the major contributing factors which could potentially alter reading time would principally be the luminance of the window or the position of the window relative to the test subject.
- Although the number of letters to be counted varied from test to test (obviously so that test subjects would not notice over time that each test had the same number of letters to be counted), there was three important mitigating factors.
    - Because the letter they were searching for in any of the visual tests could appear anywhere in the paragraph and because the paragraphs were all of a similar length the test subjects would ultimately scan a similar amount of text in all of the experiments.
    - The average duration for the letter count part of the visual test can be divided by overall number of times the letter does appear in the middle paragraph to yield a per-letter average which could then be used as a basis for comparison regardless of the total number of the times the letter actually did appear in the text.
    - The letter count is also analyzed in another way which is unaffected by average letter count duration. When test subjects reached the end of the middle

paragraph they read aloud the number of times they believed that letter appeared in the text (not unlike the Landolt ring test where they read out the number corresponding to the slits position on the ring's edge). From this the standard deviation from the correct number of times the letter appeared in the text was calculated. A smaller standard deviation would indicate that overall, test subjects answers were equal or at least close to the correct answer, while a larger standard deviation would indicate that overall, test subjects answers were farther from the correct answer.

These test results can be analysed separately and in relation to test subject's subjective rating of visual comfort, indices rating for glare likelihood and also recommended lighting standards for optimized productivity in the workplace to see if any correlations potentially exist. Subjects were assigned a number (from 1 – 48). Each two subjects (i.e. subjects 1 and 2, 3 and 4 etc) were then assigned a different test series order (although the same test was always presented under the same luminous conditions regardless of the order in which they were shown) to remove the effects of learning (getting more efficient at the test the more it was performed). In all, there were 24 permutations of the test order. In other words, for every two users who performed the tests in any given order, there are 46 other users who performed the test in a different order (see appendix five).

2.7.2 Subjective Assessment (User Rating)

At the conclusion of each test run through, test subjects were asked to subjectively rate their visual comfort levels. Subjects were told that there was no 'right' or 'wrong' answer for this portion of the experiment and that they should simply rate how they felt during the test under those specific lighting conditions.

Below is the rating system used by test subjects to subjectively indicate their visual comfort levels after each test run. The users' subjective assessment was documented to correlate user perception, luminance ratio, glare source position and task performance.

Satisfactory Conditions		Conditions with noticeable problems		Conditions with annoying problems		Conditions with intolerable problems
1	**2**	**3**	**4**	**5**	**6**	**7**

Figure 2.23 Subjective Assessment Scale used by users in experiment

Test subjects were asked to circle the number under or between the heading(s) they felt most closely represented the lighting conditions in any particular ratio setup. They filled this out in between each test. The different types of conditions which test participants were asked to circle were shown to them prior to the test and are described below:

Satisfactory conditions: There are no problems at all with the environment in terms of lighting. You feel that you could work under these conditions in an office for extended periods of time without experiencing any visual discomfort.

Conditions with noticeable problems: You notice particular areas in your field of view which is brighter than the surrounding environment but it is nothing which would cause you any discomfort nor anything for which you would either change your work habits or about which you would complain.

Conditions with disturbing problems: The lighting conditions are disturbing you and are hindering your ability to perform your task. If you were to work under these conditions for an extended period of time you would complain or move to another desk perhaps to eliminate the problems.

Conditions with intolerable problems: The lighting conditions are unacceptable to you. You would not want to work in these conditions and would complain about them straight away.

2.7.3 User Information Documentation

Test subjects were required to fill out a simple survey. The survey (see appendix **four**) documented some general data regarding the subjects e.g. age, gender, eye condition etc. This data was recorded and analysed to check if any possible correlations became apparent between particular subject characteristics and subjective assessments of lighting conditions and visual test performances. The opportunity exists for these possible correlations to be used to identify and document possible avenues for future glare research relating to particular user characteristics. The survey and reasoning behind the questions is illustrated and documented below.

VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wananga o te Upoko o te Ika a Maui

Test Subject Survey

Personal Data

1 - Age:

2 - Gender: **Male / Female (please circle)**

3 – Height: **(cm)**

4 - Eye colour: **(e.g. brown)**

5 - Do you wear corrective lenses when working at a computer?:

6 - If yes, what kind? **Contact lenses / Spectacles (please circle)**

7 - Please specify what for: **(e.g. far-sighted)**

8 - Do you wear sunglasses or tinted lenses on bright sunny days when outside? (please circle appropriate answer)

1	2	3	4	5
Never		Sometimes		Always

9 - Do you wear sunglasses or tinted lenses on overcast days when outside? (please circle appropriate answer)

1	2	3	4	5
Never		Sometimes		Always

Workplace Description

10 - Do you have windows in your office? Yes / No (please circle)

11 - Which geographical direction do they face? **(e.g North-East)**

12 - In which size category would you place them?

Small **Medium Large** **(please circle)**

Figure 2.24 User survey page (continued next page)

13 - The window primarily provides a view of ….(circle only the most important)

Landscape Cityscape Neighbouring buildings Water bodies Sky

Traffic areas (street, parking lot, railroad)

14 - How would you characterize your *computer* work tasks?

Word processing and text editing communication Data creation graphic applications (layout, CAD, animation)

other: (please specify)

15 - Where do you sit relative to the windows in your office?
(e.g. windows in front / behind / to the right / to the left / all around).

16 - How long do you spend in front of a computer during a normal working day?

<u>Well-being and Test/Workplace Comfort</u>

17 - How do you feel about your work environment? (please circle)

1	2	3	4	5
Very negative		Average		Very positive

18 - How well did you sleep the night before participating in this test? (please circle)

1	2	3	4	5
Very badly		Average		Very well

19 - How do you judge the temperature in this test office?

1	2	3	4	5
Too cold		just right		Too warm

20 - How would you describe your current physical condition?

1	2	3	4	5
Very poor		Average		Excellent

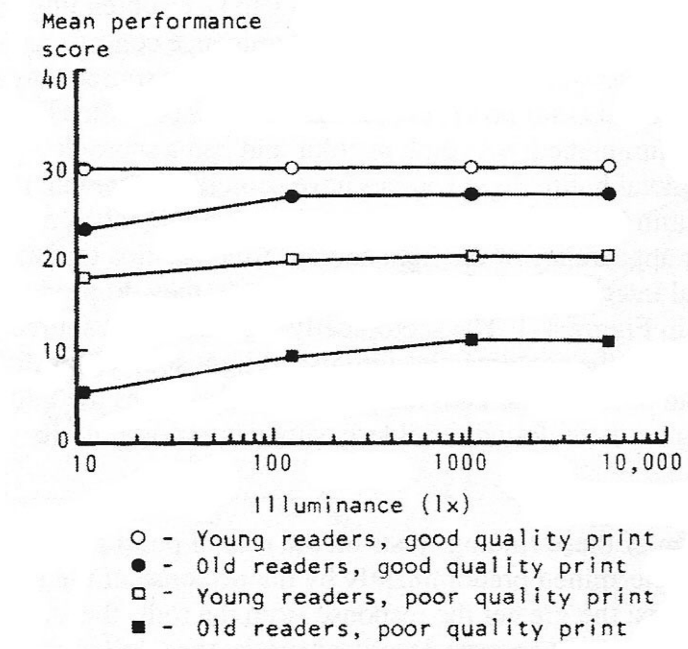
21 - How would you describe your current emotional condition?

1	2	3	4	5
Very poor		Average		Excellent

22 - What type of illumination do you prefer? (please circle)

Daylight Electric lighting No preference

The personal data section notes some fundamental characteristics of the user which could affect their experience of the various luminance distributions. Although historically, age has not shown a strong correlation with visual comfort appraisals (see section 3.0); some correlation between productivity, luminous conditions and age has been found in previous studies (see figure 2.25) so age was documented in the survey.



Mean performance score for proof reading good and poor quality text, plotted against illuminances for young (18 - 22 years) and older (49 - 62 years) subjects. The performance score was calculated from the accuracy of proof reading with a bonus for speed. The maximum possible performance score was 35 (After Smith and Rea, 1978).

Figure 2.25 Example of study results showing links between user characteristics, lighting conditions and task performance

Height was documented, as the subtle differences in viewing angle between the user's eyes and the VDT area were not anticipated to cause but may have caused differences in visual comfort or productivity as viewing angle may have a small effect on the apparent brightness of an LCD screen (Occupational Health, 2005). The rest of this section was documenting information regarding the visual system and attempts to gain a quick interpretation of the user's sensitivity to daylight and condition of the eyes (by noting any eye deficiencies and how the user would react to different day-lit conditions) which could affect user performance.

The second survey section, 'Workplace Description' details the user's normal working conditions with a particular emphasise on layout and likely workplace tasks (window sizes, positions and a record of the types of generic tasks they normally perform). These were documented as it gives a representation of the day-lighting conditions in each user's work area and potentially an indication again as to how sensitive a user may be to window luminances given their typical exposure in their normal working environment to daylight. By analysing user's subjective assessments and visual test performance against the documented workplace descriptions, this study can begin to assess the impact of a person's typical working environment on their sensitivity to various window luminances/daylight glare.

The final section of the survey documents subjects' assessments of their personal and workplace wellbeing, values and test office conditions. This was to allow an analysis of the more intangible qualities regarding office quality and values inherent in individual subjects (physical/emotional condition, preference of daylight or artificial light) with respect to visual comfort levels and test performance. The results from the survey were divided up according to particular visual comfort response levels or a particular response type from within the survey so that the average characteristics (across all of the survey questions) for all participants who subjectively assessed any given test at any rating on the continuum or answered a survey question in a particular way could be analysed for possible trends or correlations (see section 6.0 for greater detail).

2.7.4 Outline of Analysis

The experiment recorded both subjective and objective measures. The subjective measure was test subjects' completely unbiased, subjective assessment of the quality of the lighting conditions (see section 3.0) at the conclusion of each visual test. From this the results were analysed as follows
(see sections 3.0, 4.0, 5.0 and 6.0 of this thesis for the results):

- The total number of subjects from the test population who rated each lighting condition at each assessment point - this was to show the overall distribution of the test population's subjective assessments across each of the nine luminance distributions (a specific permutation of window brightness and workplace/computer position).

- The average subjective assessment for each of the nine luminance distributions - this was used to show the overall average subjective assessment rating for each luminance distribution for the entire test population.

- The overall range of subjective assessment ratings for the entire test population for each of the nine luminance distributions - this was to illustrate whether the subjective assessments for the entire test population had a small or large standard deviation from the mean.

- Using the survey (see 2.7.3), an analysis of the overall characteristics of every test participant who subjectively assessed a specific luminance ratio at a particular point along the subjective assessment scale (section 6.0).

- The boundary of comfort and discomfort (BCD) - this is defined as the point along the assessment graph where the average assessment (line of best fit) became '3' or 'Conditions with noticeable problems'. Using the formula for the line of best fit and substituting '3' in for the 'Y' (subjective assessment) value to determine 'X', the specific luminance ratio where the subjective assessment crosses the 'BCD' can be found. The BCD luminance ratio for each window position is compared to examine the effect that window position had on subjective assessment of visual comfort.

The objective assessment (visual performance test – section 4.0) was analysed in the following ways:

- The average number of errors and test duration was recorded for each lighting condition. The results were then arranged in order of lowest window luminance to highest (within each window position). In this way the impact on productivity (on average) as window luminance increases (gradient of trend line) can be calculated. Using this graph, the data can be extrapolated to predict the likely impact on productivity at a variety of different likely office window luminances.

- The number of errors (specifically from the Landolt ring part of the visual test – defined as the number of times on average where the test subject was unable to find the slit within the four second time limit) on particular areas of the screen (e.g. left/right or top/bottom) were also examined to assess the impact (if any) of window position on subject's ability to find the slit in particular areas of the screen.

Correlations between the two different assessment types (possible links between subjective assessment responses and visual test performance) are discussed in section 5.0:

- Exploring the possibility of a direct link between visual comfort and the number of errors test subjects were making (errors in this case being defined as both the number of slits test subjects missed during the Landolt ring portion of the visual test and the standard deviation of subject's answers during the letter counting portion of the test).

- Possible links between subjective assessment and visual test duration (which as discussed previously is as much a part of test performance as the number of errors) are also examined in this section.

3.0 Subjective Assessment Analysis Outline

The subjective appraisals were based upon a sample size of 48 subjects who were recruited by voluntarily responding to an email or expressing interest to the researcher through those who had been emailed. Subjects were required to meet the following criteria after volunteering for the experiment:

- Age - be between the age of 18 and 65 years old. In New Zealand, according to census data, this is the average range of ages for the working class population where the typical age of retirement is 65 years old. With respect to similar research into subjective appraisal of lighting conditions, Weinold & Christoffersen (2006) used a sample range of 20 – 59 (the average age being 43.4). Kasahara et al (2006) on age ranges in their study simply wrote "subjects consist of eleven males (eight in their twenties, one in his thirties and one in his fifties) and one female (in her thirties)" (p. 98). Kim et al (2007) said their sample population ranged in ages 21 – 26 (with an average of 22.6). Sendrup (2001) did not state specifically in this paper the age ranges but did say "The number of subjects in the different age groups (20-30 years, 30-40 years, etc) was almost equal, but there was a slight predominance of women in both investigations." (this difference was probably not an issue – see next bullet point regarding gender effects). It appears that the selection of different subjects whether it be a large or small age range is not predicted to have a powerful impact on subjective appraisals (see next bullet point) and in any case the ages of the users selected for this research conforms to previous sample population ranges. The subjects' age range for this experiment was 19 – 56 (with an average age of 26.3 years old meaning the experiment was weighted towards the younger demographic).

- Gender balance - an equal number of males and females were tested (24 of each). This was to remove any possible gender bias although gender was not foreseen to be a factor affecting visual comfort levels (although this was considered under user-group responses).

> "The absence of sex and age differences is generally consistent with the literature. A thorough review could locate no study that reported age differences in lighting preferences across the range studied here. Both Berruto et al (1997) and Boyce (1973) looked for, but did not find, age differences in preferred luminous conditions. Veitch and Newsham (1998) did not observe sex differences in environmental satisfaction or lighting quality. Leslie and Hartleb (1990) reported sex differences in preferred illuminance levels, but their sample included 23 men and only 6 women (the unequal sample size throws the significance test into question and also risks the possibility that the small sample of women was not as representative of the population as the larger sample of men). Knez (1995) and Knez and

Enmarker (1998) report sex x lamp type interaction effects on measures of affect (men and women had different mood responses to cool-white versus warm-white fluorescent lighting), but these effects were in the opposite directions in the two studies. Taken as a whole, the literature does not provide firm support for the notion that age or sex influence preferred luminous conditions for office work." (Veitch and Newsham, 2002, p. 205 - 206).

Once 24 of either gender was reached, additional volunteers were thanked but told their participation was not required.

- VDU workstation experience - have a VDU workstation at home or their place of work where they spend at least some period of the day using the VDU.
- Availability - be studying or working in New Zealand at the time of participation.

3.1 Subjective Assessment Front (Window in Front of User)

This section examines the trends among the test population's subjective assessment when the window was in front of the users' field of view.

3.1.1 Total Number of People

The total number of people from the test population who rated each test at a particular comfort level along the continuum is examined here. The average is an important factor to consider (see section 2.1.2, 2.2.2 and 2.3.2) but it is a product of the distribution of the test subjects' subjective assessments, so it is also important to consider this to truly understand what the average means.

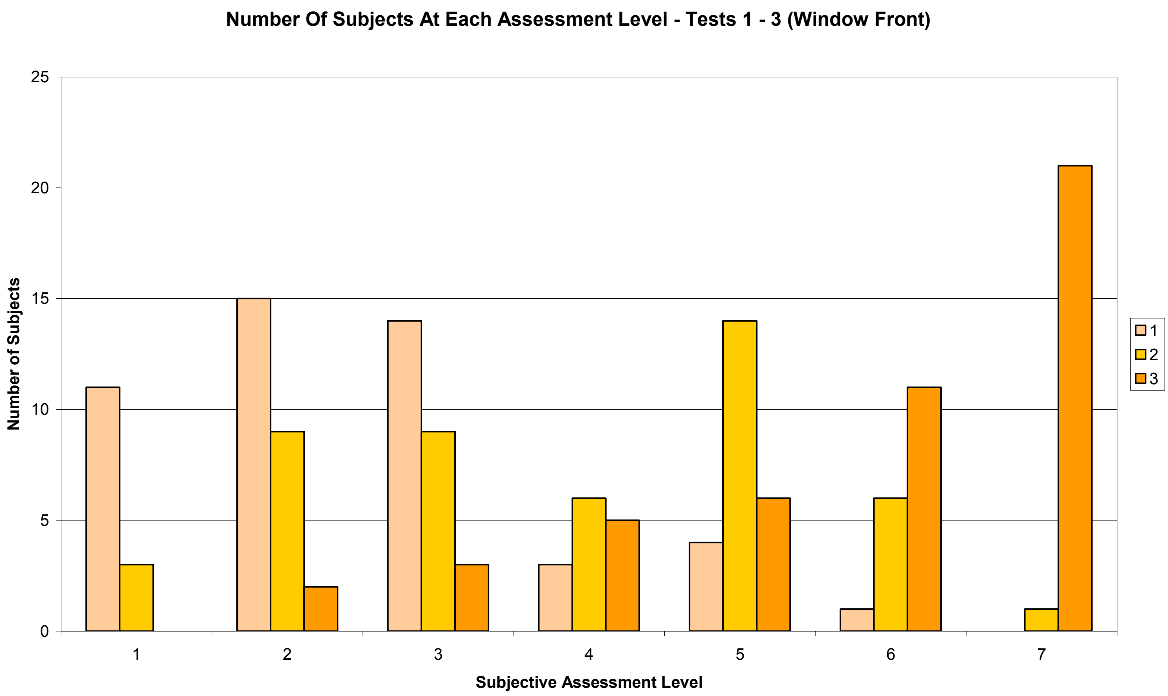


Figure 3.01 Subjective assessment distributions of responses for tests 1 - 3 (window front variation)

Test number 1 was made up of the lowest window luminance (or window:VDU ratio) with the user facing the window (see section 2.3). Despite some areas of the window having luminances slightly more than 300 cd/m2 higher than the recommended field of view maximum and the subsequent ratio between the task area (laptop screen) and artificial window being slightly outside the recommended maximum for visual comfort of 10:1 (13.6:1 in this test run through) the distribution of subjective assessment responses for visual comfort was still heavily weighted towards the low end (satisfactory to noticeable brightness). 80% of the test population were at or below the BCD mark of '3' which begins to support the theory that the older maximum luminance and luminance ratio recommendations may be out-of-date and some variation in these may be wise. To assess how large this variation may need to be (at least for this particular office layout 'window in front') we move onto the higher luminances and luminance ratios to examine if this distribution trend continues or not. Intuitively we can expect that as the window luminance and subsequent ratios increase, the distribution of responses will shift to the right. How fast this shift occurs between each successive test (within each position) will help identify the likely band of luminances and ratios where the BCD exists for the majority of the test population. It also identifies where further study regarding luminance ratio ranges should be focused to help refine the BCD luminance or ratio. Another possibility is to redefine the definition of the factors used in these rule of thumb ratios (specifically the background luminance or adaptation luminance) rather than redefining the luminance ratio recommendations themselves. The adaptation luminance (E_v/π) which unlike the traditional definition of background luminance actually takes into account the effect of light reaching the eyes from the glare source itself may be a better value to use in the ratios. If we use this latter definition as background or base level luminance to break down the ratios between the glare source and the task area to something like glare-source:adaptation-luminance and adaptation-luminance:task then the ratios are 3.6:1 and 3.7:1 respectively. Both fall well within the 10:1 or 40:1 maximums and coincide with the overall subjective response distribution.

Test number 2 increased the luminance of the window to 3268.39 cd/m^2 and at the same time the ratio of screen luminance to task area luminance to 27.2:1. As was expected the distribution of subjective responses shifted to the right. 44% of subjects were on or below the BCD with another 44% being either a '5' (annoyed by the lighting conditions to a point where they believed it would cause them discomfort and affect their work habits) or higher. As the average window luminance is almost 1800 cd/m^2 higher than the recommended maximum it is no surprise that the distribution has shown a detrimental shift. However, only 1 subject (or 2% of the population) actually found the conditions intolerable. If the subjective appraisal distribution is examined in relation to the adaptation luminance ratios (below) it is difficult to reconcile these values with subjective appraisal as both are well with in the 10:1 or 40:1 talked about maximums. It would appear that as window luminance increases, this adaptation variable means small increases in the ratios will result in noticeable shifts in visual comfort. In terms of this experiment this makes sense. Even if the ratios themselves did not change much or at all, the luminances used to derive the ratios and the adaptation level are much higher (more than twice the previous window brightness setting). It could also be the variance between the two adaptation luminance ratios used. In the previous variation the ratios were very close together (2.7% difference) and here the variance is much larger (39% difference) suggesting that the variance in the two ratios may play a factor and the closer they are to each other the better. A small variance in the two ratios indicates that the luminance level the eye is adapted to is the same factor away from the task luminance as it is from the glare source (an equilibrium of adaptation in a sense). A larger variance indicates that the factors between the window, adaptation level and task area are different meaning that adaptation level could be too low for the window luminance to be comfortable or similarly, too high for the task area luminance to be comfortable. Further extensive research would be required to establish this. If using an adaptation luminance ever became the norm in quick ratio calculations for daylit spaces then designers would need to be aware that small differences in the ratio can result in large shifts in overall comfort levels and that a large difference in the two adaptation ratios (named below) may be undesirable.

- 4.1:1 (window to adaptation luminance)
- 6.7:1 (adaptation to task area luminance)

It is evident now with a window luminance of 6332.65 cd/m^2, creating a ratio between the glare source and task area of 46.9:1, that visual comfort is being noticeably hindered. This becomes especially evident with the largest percentage (44%) of subjective responses being a '7' (Intolerable lighting conditions which would immediately cause the subject to complain and change their workplace setup to alleviate the problems). In fact 89.6% of the population assessed the conditions above the BCD level. If adaptation luminance ratios are examined:

- 4.5:1 (window to adaptation luminance)
- 10.4:1 (adaptation to task area luminance)

The resulting visual comfort levels could be a product of the adaptation to task area luminance which is slightly above the 10:1 recommended max (although still far below the 40:1). It could also be a product of the variance issue discussed previously. The variance has increased from 39% in the previous setup to 131% difference (due to disproportionate increases in adaptation level, reflected laptop screen luminance and window luminance).

3.1.2 Subjective Assessment Average and Range

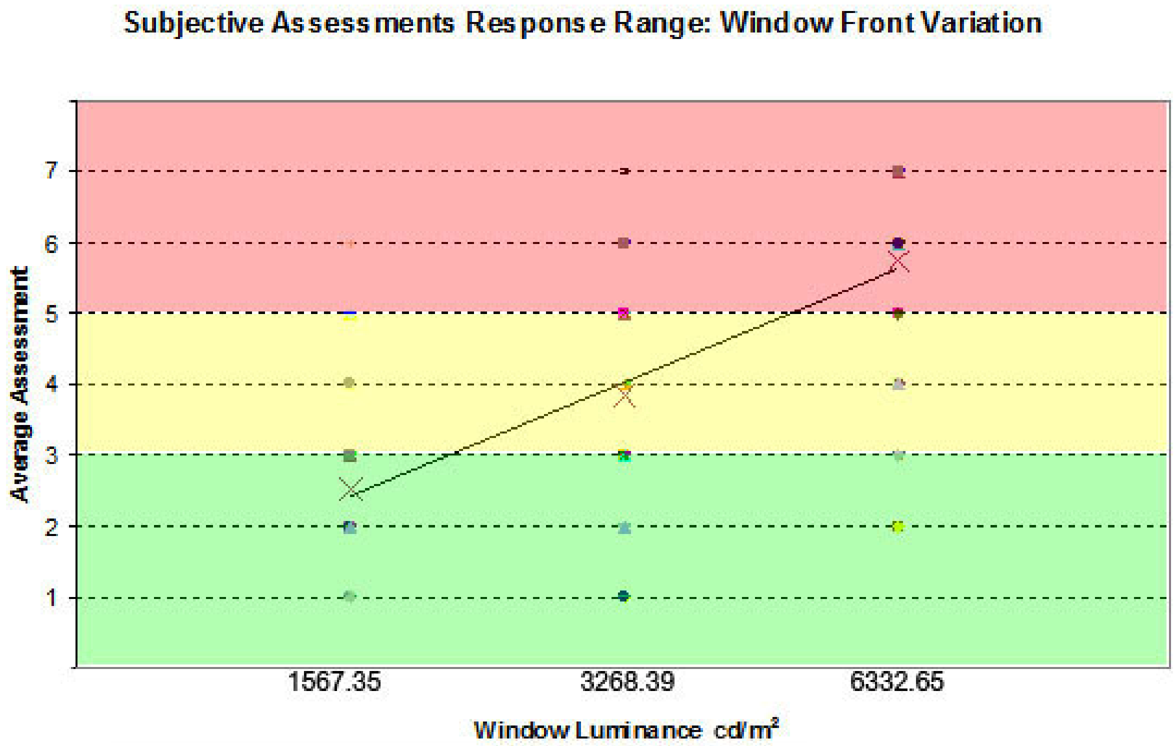


Figure 3.02 Subjective appraisal distribution and overall trend of responses for tests 1 - 3 (window front variation)

	Test 1	**Test 2**	**Test 3**
Mean	2.52	3.85	5.73
Min	1	1	2
Max	6	7	7
Standard Deviation	1.27	1.58	1.47

Table 3.01 Subjective assessments mean, minimum, maximum and standard deviation - Window front variation

Ratio/Variance	Test 1 (window:1567 cd/m^2)	Test 2 (window: 3268 cd/m^2)	Test 3 (window: 6333 cd/m^2)
Window:Task Area	13.6:1	27.2:1	46.9:1
Window:Adaptation	3.6:1	4.1:1	4.5:1
Adaptation:Task Area	3.7:1	6.7:1	10.4:1
Difference % (adaptation)	2.7%	39%	131%

Table 3.02 Luminance ratios and percentage difference in adaptation ratios – Window front variation

The average response rates for tests 1 – 3 with the window directly in front of the users' FOV can be used to find the average rate at which the test population's visual comfort levels declined as the luminance ratios and maximums were increased. It is important to note again that these tests were presented to subjects in a non-linear order and that despite this, when the results were arranged back into order of increasing luminance there was a clear upwards trend in responses (declining visual comfort). Overall, the responses for test number 1 suggest that at an average window luminance of 1567.4 cd/m2 and luminance ratio of 13.6:1 (between glare source and task area) causing only a minor variance (2.7%) between the two adaptation ratios, overall visual comfort is not being hindered as the lighting conditions have no 'noticeable problems' (although this is not annoying conditions, over an entire working day if it is noticeable under short-term exposure then it could realistically become annoying).

The middle order window luminance brought the average up over the BCD line although it is closer to noticeable than annoying (at least in the short-term). According to the BCD rule used in this experiment the recommended ratio for this layout would likely be somewhere between the lowest and middle order window luminances or luminance ratios which were tested (this is examined in greater detail for this layout in section 3.1.3). While the gradient is similar, the rate at which the average comfort level responses of the test population declined increases slightly between the middle and highest ratios which were tested. This suggests a luminance threshold whereby visual discomfort will increase at an increasing rate after it is passed. The average assessment for the highest ratio in this layout was more than annoying ('5') although it was closer to this response than it was to intolerable '7'. As the ratio between window and task area (46.9:1) was outside the recommended limits as was the maximum recorded field of view luminance (6332.65 cd/m^2), these results support current standards although they were still insufficient to produce an average response of intolerable conditions despite being well outside the recommended limits. Because no real standards exist regarding adaptation ratio variances only observations from this experiment can be used in comparison to the overall visual comfort levels observed in the experiment. In this position the relationship between window luminance and adaptation ratio variance was almost exponential. Suffice to say, that a small variance was observed with higher overall visual comfort levels and that as window luminance increase, so did variance and overall visual comfort declined. In theory the variance could be reduced as window luminance increased by increasing task area luminance although this is not feasible as VDU luminances have a maximum setting of approximately 100 cd/m^2 and if it could be increased at the same rate as window luminance to maintain low adaptation ratio percentage differences, then the VDU screen itself could contribute to the glare from its high luminance.

3.1.3 Borderline of Comfort and Discomfort (BCD)

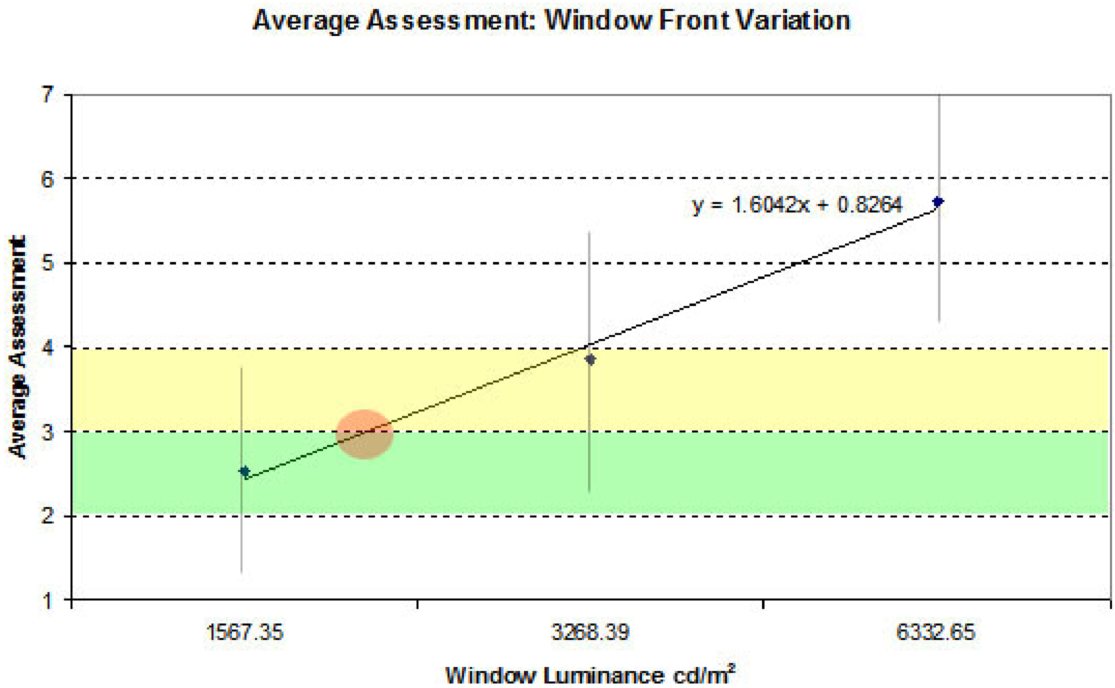


Figure 3.03 Average subjective assessment tests 1 -3 (window front variation) trend line with S.D (grey lines) and BCD (red circle) identified

This section identifies the BCD window luminance and the luminance ratios (for this layout) based upon the line of best fit for the average subjective assessments. The rates of increase in overall subjective appraisal between each window setting are documented here:

Tests 1 → 2	Tests 2 → 3	Overall position
Appraisal +1.33	Appraisal + 1.88	Appraisal + 1.6
Tests 1 → 2	**Tests 1 → 3**	
+ 52.8%	+ 127.4%	

Table 3.03 Actual and percentage increases in subjective assessment between the different tests - Window front variation

Visual comfort declined 41.4% faster between the middle and highest order tests which can be seen either in the average increase in appraisal between each variation or in the relative percentage increases between the lowest order variation and the middle and highest order variations.

The border line of comfort and discomfort (BCD) when the window was in front of the user was:

- Window luminance of 2162.7 cd/m^2
- Window to task area ratio of 18.5:1

The BCD is conservative and identifies the point of a glare source causing discomfort as the point where average appraisal of the glare source only becomes noticeable. Even as such the ratio is well outside the 10:1 limit. With a similar method to that used in finding the BCD luminance (calculations can be found in appendix one), the likely adaptation level at this window luminance can be found based on the recorded adaptation luminances. Therefore, the likely adaptation luminance at the BCD is 560.15 cd/m^2. Using the BCD luminance, the adaptation luminance and the likely task area luminance (same method as above – see appendix one) the adaptation ratios are as follows:

- 3.86:1 (window to adaptation luminance)
- 4.80:1 (adaptation to task area luminance)

This represents a percentage difference in the ratios of 24.35%. Comparison to other BCD results will help test whether the variance in the two ratios may have an impact on overall visual comfort levels.

3.2 Subjective Assessment Side (Window 90° from User FOV)

This section examines the trends among the test population's subjective assessment when the window was in 90° left of the users' field of view.

3.2.1 Total Number of People

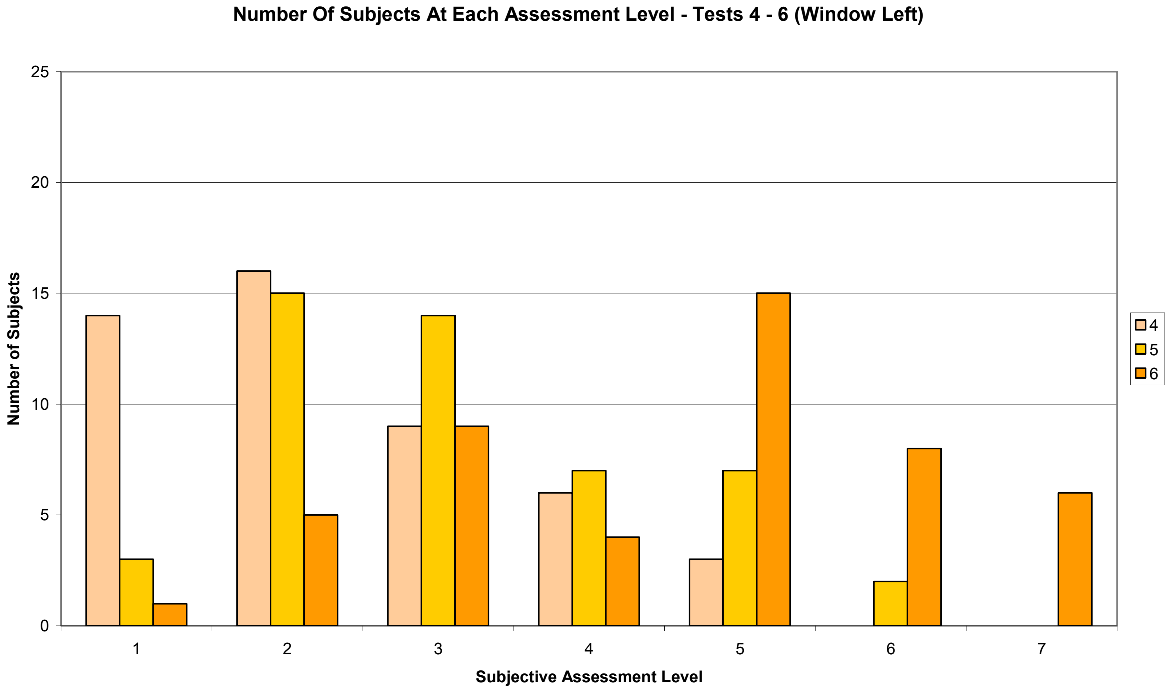


Figure 3.04 Subjective assessment distributions of responses for tests 4 - 6 (window front variation)

Tests 4 – 6 consisted again of the lowest to highest luminance ratios (respectively), however this time the subjects were placed at the work station, perpendicular to the artificial window (window 90° to the left of the subjects). Once again the lowest window luminance (test number 4) with a window to task area ratio of 14.9:1 resulted in the majority of the test population assessing the conditions at the BCD line or below with 81.25%. Also and unlike test number 1 (which had the same luminance ratio between the window and the laptop screen but had the window in front of the user) which had a single response at ‘6’, the highest response for this run through was a ‘5’. Having the window 90° to the work station also resulted in an increase in the number of subjects who were completely satisfied (responded with a ‘1’) with the lighting conditions and experienced no sensation of glare (from 23% to 29% - when compared to test 1) which reinforces the notion that it is best to have workstations perpendicular to a day-lit building façade. 18.75% of subjects assessed conditions above the BCD and of that portion, only 33% (or 6.25% of the entire population) found the conditions annoying or noticeable to the point that it would affect their work habits over an entire working day. Again the distribution of responses suggests (at least for this luminance ratio level) that some variation on the old standards may be reasonable as the 10:1 limit is exceeded by almost 50%. If the definition of L_b was taken to mean the average FOV luminance (incorporating the impact of the glare source on the eyes instead of ignoring it) then the resulting luminance ratios are:

- 4.8:1 (window to adaptation luminance)
- 3.1:1 (adaptation to task area luminance)

Once again these are well within the current 10:1 range although the difference is larger (35%) than its front variation counterpart and still visual comfort was improved on. It may well be percentage difference is not a factor or if it is, it is only relevant to certain glare source positions and placing the window in the recommended perpendicular position mitigates the increased variance. The window luminance itself was at the lowest setting which may have also helped mitigate any percentage difference effects.

The test 5 variation produced a window to task area luminance ratio of 28.4:1. The luminance distribution is within the 40:1 but well outside the 10:1 limit, and the window luminance is in excess of the recommended maximum by a factor of more than two. The distribution of responses for test number 5 (the middle ratio) moved to the right like its counterpart test number 2 in the front position. However this shift is less pronounced than in test number two. This could possibly be explained by and at the same reinforce the current daylighting design recommendation of having day-lit work stations perpendicular to the glazed façade. While the luminance ratio has changed slightly between test number 2 and test number 5, the change in position is the only major variable which has been altered and now 56.25% of users responded at or below the BCD level compared with 44.00% in the prior. This clearly demonstrates the principle that with intelligent daylighting design, the impact of the same or even higher window luminance ratios on comfort can be reduced (whether or not this trend continues into productivity levels is examined later in section 4.2). The adaptation luminance ratios are as follows:

- 5.5:1 (window to adaptation luminance)
- 5.2:1 (adaptation to task area luminance)

Both of these values are well within the 10:1 recommended limit although slightly up on the previous variation suggesting again that it only takes small shifts in this ratio (less than 1) to have a relatively large impact on visual comfort levels. The variance in these figures is greatly reduced (5.8%) from the previous variation due to disproportionate increases in task brightness and adaptation levels which may have contributed to higher BCD. This is because in this position the relative increase in screen luminance (and possible reflections and contrast reduction) as window luminance increases is less than its front variation counterpart.

Test number 6 used the highest window luminance of 6332.65 cd/m^2 (creating a window to task ratio of 50.7:1) and had a much larger response rate above the BCD like its front orientated counterpart (test 3). The number of responses above the BCD line rose to 68.75%; however this is still more than 20% below the percentage for when the window was in front of the user with the same luminance even though the window to task ratio is well above both the 10:1 and 40:1 possible limits. One of the most noticeable changes was the decrease in the number of responses at ‘7’ to 12.5% of the population, down more than 30% compared to the same test with the window in front of the users. Over all of the luminances and luminance ratios used in this office setup, the overall distribution of responses was lower than those from tests 1 – 3. As the only major variable which was changed in this run through of the experiment was the relative position of the window, all these results support the recommendation that daylit workstations should be placed perpendicular to a daylighting façade. Likely reasons for these results are firstly, the glare source is only visible in the peripheral areas of the field of view and secondly, while the illumination of the surfaces in the zone is virtually unchanged, there is a minimized amount of light either going directly onto the screen reducing contrast or into the subject’s eyes (either from reflections off of the screen or directly from the glare source). The adaptation luminance ratios are:

- 6.4:1 (window to adaptation luminance)
- 7.9:1 (adaptation to task area luminance)

Both of these figures are below the 10:1 limit although as such they do not reconcile well with the distribution of appraisal responses for this variation. However, as has been observed in the previous variation it only takes a small increase in the ratio to show dramatic changes in comfort levels across the test population. It may be that using an adaptation luminance ratio means that the comfort band is across only a small range of ratios (in comparison to 1:3:10:100 etc) but that this still incorporates a wide range of possible window luminances. The variance in these ratios is 23.4% and although quite large, it is much lower than the front variation counterpart of 131%.

3.2.2 Subjective Assessment Average and Range

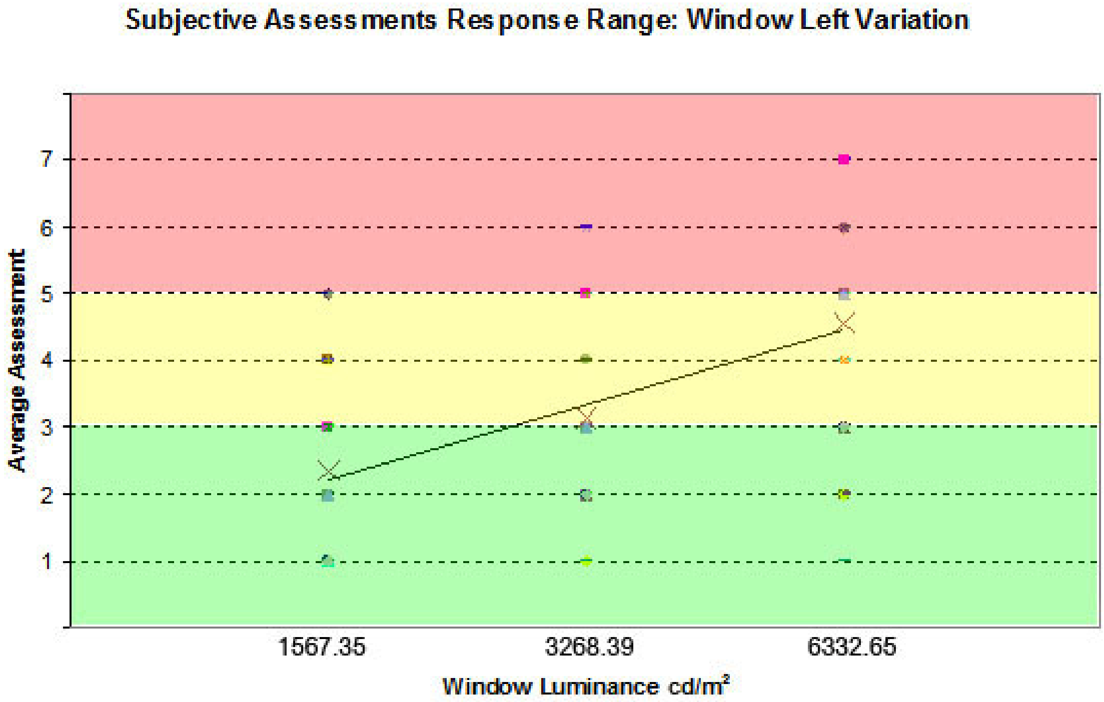


Figure 3.05 Subjective appraisal distribution and overall trend of responses for tests 4 - 6 (window left variation)

	Test 4	Test 5	Test 6
Mean	2.33	3.13	4.56
Min	1	1	1
Max	5	6	7
Standard Deviation	1.21	1.30	1.62

Table 3.04 Subjective assessments mean, minimum, maximum and standard deviation - Window left variation

Ratio/Variance	Test 4 (window:1567 cd/m^2)	Test 5 (window: 3268 cd/m^2)	Test 6 (window: 6333 cd/m^2)
Window:Task Area	14.9:1	28.4:1	50.7:1
Window:Adaptation	4.8:1	5.5:1	6.4:1
Adaptation:Task Area	3.1:1	5.2:1	7.9:1
Difference % (adaptation)	35%	5.8%	23.4:%

Table 3.05 Luminance ratios and percentage difference in adaptation ratios – Window left variation

The average responses for tests 4 – 6 with the window perpendicular to the workstation show a decline in overall visual comfort of the population as the window luminance was increased again. However, the rate of the decline is lower in comparison to the previous layout. Test 4 which presented the lowest luminance ratio (14.9:1 between window and task) indicates that overall, visual comfort is not being negatively affected by the lighting conditions with average subjective response being clearly below the BCD line (and this is despite the window to task ratio being in excess of the 10:1 limit). In fact in this position the average subjective response for the middle order window luminance was only marginally higher (0.13 or 2%) than the BCD line suggesting that because of this change in position, a glare source with the same luminance is less detrimental to comfort than in the window front variation. The gradient is much shallower between these lower order window luminances indicating also that the rate at which visual comfort declined as the window luminance was increased has also been reduced. The gradient between the middle and highest order window luminances increases, suggesting once the BCD threshold is passed, the rate of reduction in visual comfort as window luminance increases will also increase. The average assessment for the highest window luminance in this position is well above the BCD; however it is still under ‘annoying conditions’ or ‘5’, which reinforces the notion that it is beneficial to put day-lit workstations perpendicular to windows. Overall, the rate of decline in visual comfort and test averages are less in this position.

The larger difference between the adaptation ratios observed in the lowest order window luminance was a product of lower adaptation levels (as less direct light from the window reaches the vertical plane of the eye) in relation to the same window luminance. Adaptation levels rose at a faster rate than task luminance which resulted in the closer variance in the middle order test. The larger difference observed in the highest order test (test 6) where the lowest overall visual comfort levels were observed suggests that there is a greater tolerance to that difference when the larger ratio is between adaptation and glare source luminance than when the larger ratio is between adaptation and task area luminance (however it could also be a result of using recommended office layouts - discussed in section 2.3). Further research is required to establish the specific impact of these factors on visual comfort.

3.2.3 Borderline of Comfort and Discomfort (BCD)

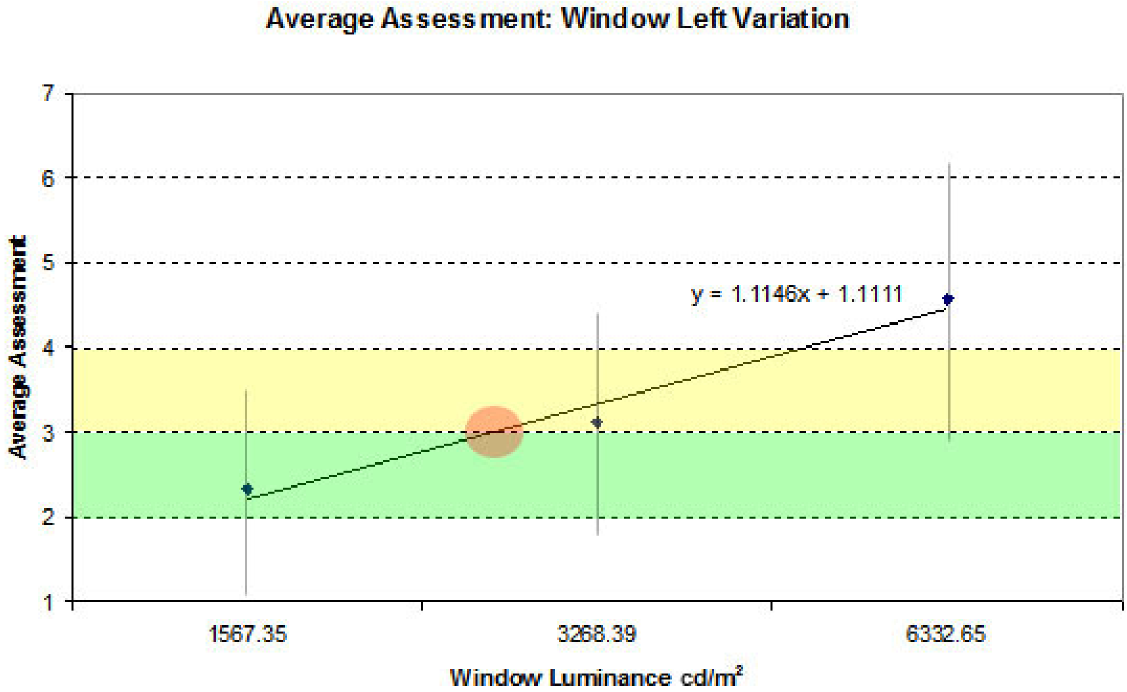


Figure 3.06 Average subjective assessment tests 4 – 6 (window left variation) trend line with S.D (grey lines) and BCD (red circle) identified

Once again there was a noticeable increase in the rate of increase in subjective assessment between the lowest and middle order tests and the middle and highest order tests. There was a 75% increase in the rate of increase between the former and latter variations although it is important to note that the increase in window luminance between the middle and highest order variations is almost twice the increase between the first two.

Tests 4 and 5	**Tests 5 and 6**	**Overall position**
Appraisal + 0.8	Appraisal + 1.4	Appraisal +1.11
Tests 4 → 5	**Tests 5 → 6**	
+ 34.3%	+ 95.7%	

Table 3.06 Actual and percentage increases in subjective assessment between the different tests – Window left variation

Borderline of comfort & discomfort (BCD) when the window was perpendicular to the user was:

- Window luminance of 2741.07 cd/m^2
- Window to task area ratio of 24.5:1 (see appendix one for task area calculation)

Using the same technique as for the 'window front variation', the adaptation and task area luminance which could be expected at this BCD luminance level in this position is 514.32 cd/m^2 (calculations can be found in appendix one).

- 5.33:1 (window to adaptation luminance)
- 4.60:1 (adaptation to task area luminance)

This represents a percentage difference in the ratios of 15.87%. This is much less than the percentage difference in the front variation counterpart. This supports the theory that the percentage variance in the two adaptation ratios has an impact on the likely degree of discomfort glare. The increased BCD can likely be attributed to using the recommended office layout but the possibility also exists that the lower percentage difference in the two ratios in this position mitigates the impact of the window as a glare source.

3.3 Subjective Assessment Behind (Window behind User)

This section examines the trends among the test population's subjective assessments when the window was behind the users' field of view.

3.3.1 Total Number of People

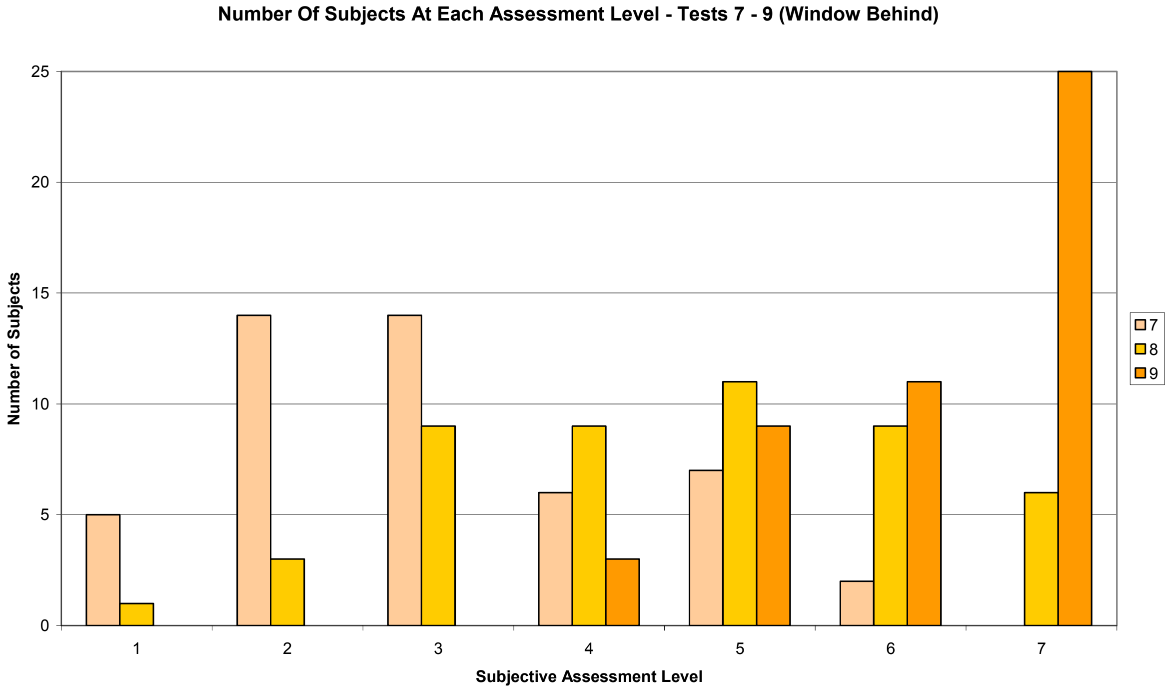


Figure 3.07 Subjective assessment distributions of responses for tests 7 – 9 (window behind variation)

The distribution of responses when the glare source was placed directly behind the users raises some interesting points. While veiling reflections (light reflected off the task area or VDU screen) which were simulated in this experiment setup to reduce task area contrast, are normally associated with disability glare only, the responses suggest some users were still experiencing poor visual comfort despite the glare source being nowhere within the FOV. Reasons for these distributions include the possibility that the reflections off the screen not only reduce task area contrast but are sufficiently high in luminance to cause visual discomfort or that visual comfort for these users includes the 'effort' it takes to perform the task. It may be that with reduced contrast, not only does test performance fall but because the visual system is required to work harder to distinguish details on the screen, this in itself is contributing to decreased visual comfort as the window became brighter. It is unlikely that luminance itself caused low visual comfort level as the laptop screen was recorded to be only 300 cd/m^2 at the highest window setting (well under recommended limits – discussed in more depth in section 5.0). Wall luminance and wall to task ratios are documented here as unlike the other layouts which had the window occupying the majority of the field of view, it was the task area and walls only which were visible during the test (the wall luminance values were for all layouts).

Window Luminance	Wall Luminance	Screen Luminance	Wall/Screen ratio
1567.35 cd/m^2	300 cd/m^2	150 cd/m^2	2:1
3268.39 cd/m^2	600 cd/m^2	200 cd/m^2	3:1
6332.65 cd/m^2	1000 cd/m^2	300 cd/m^2	3.3:1

Table 3.07 Wall and screen luminance ratios

All of these ratios are within even the most conservative of recommendations for ratios between immediate and adjacent surfaces intuitively suggesting that the layout should provide good visual comfort levels even if productivity is hindered.

The window to screen ratio (10.4:1) was lower than the other layouts for this brightness setting due to increased laptop screen luminance (from reflections) and is almost within the 10:1 limit. Test number 7 displayed the lowest window luminance and much like the previous positions which were used, the majority of the population assessed the conditions at or below the BCD level. 68.75% of the test population gave these responses. Strangely however, this is lower than both the counterpart tests from the other positions (test 1 and 4) which reinforce the possible notion that the visual system having to work harder to perform the visual test actually resulted in higher perceived visual discomfort levels than having the glare source itself somewhere within the field of view. The other possibility is that the veiling reflections cause sufficient discomfort because of the lowered adaptation levels due to not having the window within the FOV (those ratios discussed below). There were no instances in test number 7 where subjects responded as the conditions being intolerable; however 18.75% of subjects assessed the conditions has either annoying or more than annoying (a '5' or '6'). This is more than the front and side position test counterparts. The adaptation luminance ratios (including the adaptation to wall) were:

- 6.1:1 (window to adaptation luminance)
- 1.7:1 (adaptation to task area luminance)
- 1.2:1 (wall to adaptation luminance)

Although the difference between the first two values is a lot (259% despite being the lowest window brightness setting) and perhaps had some impact on comfort due to the lower adaptation levels compared to the wall luminances in this layout, the issue more likely arose from the difference in wall:adaptation:task luminance ratios since these were the principal field of view components. Here the difference is 42% which is much higher than the front variation counterpart although comparable to the left variation. If the former difference is the major factor affecting comfort levels then we can conclude that the greatly increased percentage difference in the ratios has caused visual comfort to fall beyond the other positions (with the same window brightness). If it is the latter difference then it seems that if a non-recommended layout is used, a difference of only 7% greater than the same window setting in the left variation will result in a relatively larger detrimental effect on visual comfort levels.

Another example of a window to task ratio much less than its counterpart tests, test number 8 had a ratio of 16.3:1. Outside the 10:1 which in this position may actually be a limit (noticing that the overall comfort levels for this position were lower than the others even at a ratio of 10.4:1 in the previous variation) but well within the 40:1. This variation displayed a strong distribution shift to the right. Only 27% of subjects responded at or below the BCD level suggesting that the luminance limits (both maximum and ratio) for the promotion of visual comfort amongst the majority of space users is lower when the window is behind the workstation than when it is either in front or perpendicular. Of the 73% of subjects who responded as a ‘4’ or higher, 74.3% (or 54% of the total population) found the conditions annoying or worse and 17% (12.5% of the total population) found them intolerable. These numbers are comparable to the highest luminance ratio tests of where the glare source was beside the user rather than in front or behind thus illustrating again the importance of careful placement of VDU workstations in daylit offices. In comparison to the window front counterpart, this distribution of responses still shows a greater number of subjects responding above the BCD level again suggesting that a combination of reduced VDU contrast, adaptation levels (and possibly veiling reflections) affects visual comfort more detrimentally than direct glare. Adaptation luminances for this variation:

- 7.5:1 (window to adaptation luminance)
- 2.2:1 (adaptation to task area luminance)
- 1.4:1 (wall to adaptation luminance)

Variance between the first two values was 240% which is a large figure again but probably not the most important ratio (especially since it is less than the previous variation despite a marked decline in overall visual comfort). Variance in the latter two values was 57% and this fits in with the trend of increasing variance more detrimentally affecting visual comfort. The value itself is much higher than its front and left variation counterparts possibly contributing to the lower overall visual comfort levels in this layout when compared with the others.

The highest window luminance was used for test number 9 and this resulted in a window to task ratio of 21.1:1. More than twice the 10:1 limit but well within the 40:1, previous results from this layout suggested a low overall visual comfort appraisal was likely. In this case, even with the window itself nowhere within the FOV, 0% of subjects responded at or below the BCD level and only 6.25% of the population even found the conditions as a ‘4’ with not quite annoying problems (to the point where it would likely affect their work-habits over a working day) but conditions which had more than noticeable problems. Of the 93.75% of the population which assessed the conditions as either annoying or worse, 55.6% (or 52% of the entire population) found them intolerable. It is clear that by the time the window was set at its highest average luminance of 6333 cd/m2 in this position that the FOV maximum luminance or luminance ratio had been well passed (suggesting for large area glare sources even a 40:1 limit may be too high although further testing with various window sizes would help clarify this). Luminance ratios in this layout are difficult to interpret as despite the lower window to task ratio, this is a result of veiling reflections increasing screen luminance which reduces screen contrast and actually makes visual tasks more difficult. Adaptation ratios in this variation were:

- 8.3:1 (window to adaptation luminance)
- 2.5:1 (adaptation to task area luminance)
- 1.3:1 (wall to adaptation luminance)

Variance between the first two ratios was 232% and again this is smaller than the previous variation (due to disproportionate increases in laptop screen and adaptation luminance) despite the strong decline in overall visual comfort appraisal distribution. The variance in the second two ratios was 92%; a noticeable increase compared to the previous variation correlating with a decrease in visual comfort. Further study would be required to establish the weighting of variance on likely visual comfort appraisal based on the specific characteristics of the lighting and workstation layout. Results suggest that variance can be mitigated through layout.

3.3.2 Subjective Assessment Average and Range

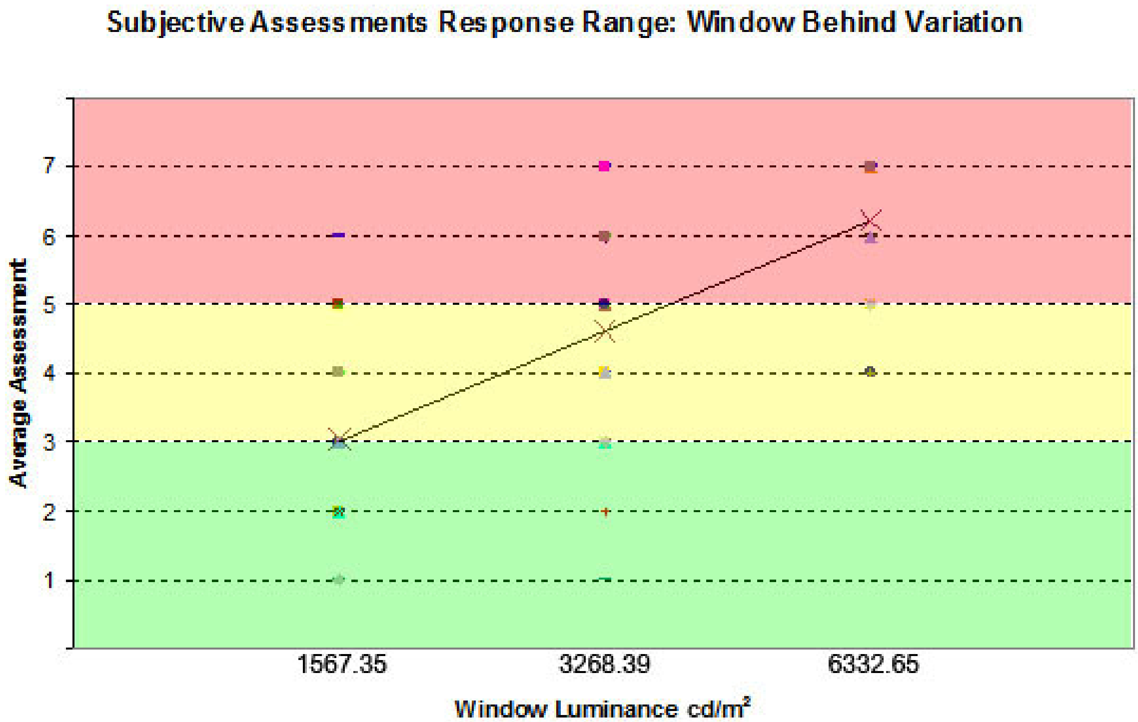


Figure 3.08 Subjective appraisal distribution and overall trend of responses for tests 7 - 9 (window behind variation)

	Test 7	Test 8	Test 9
Mean	3.02	4.60	6.21
Min	1	1	4
Max	6	7	7
Standard Deviation	1.33	1.55	0.97

Table 3.08 Subjective assessments mean, minimum, maximum and standard deviation - Window behind variation

Ratio/Variance	Test 7 (window:1567 cd/m^2)	Test 8 (window: 3268 cd/m^2)	Test 9 (window: 6333 cd/m^2)
Window:Task Area	10.4:1	16.3:1	21.1:1
Window:Adaptation (a)	6.1:1	7.5:1	8.3:1
Adaptation:Task Area (b)	1.7:1	2.2:1	2.5:1
Walls: Adaptation (c)	1.2:1	1.4:1	1.3:1
Difference % (a & b)	259%	240%	232%
Difference % (b & c)	42%	57%	92%

Table 3.09 Luminance ratios and percentage difference in adaptation ratios – Window behind variation

While the other positions showed a noticeable increase in the rate of decline in visual comfort between the lowest and middle ratio and the middle and highest ratio, the tests with the glare source behind showed an almost linear increase in this rate. A possible explanation is the fact that any glare source is reflected light from the window or walls rather than light directly from the window so almost doubling the window luminance results in a disproportionate increase in overall subjective appraisal.

3.3.3 Borderline of Comfort and Discomfort (BCD)

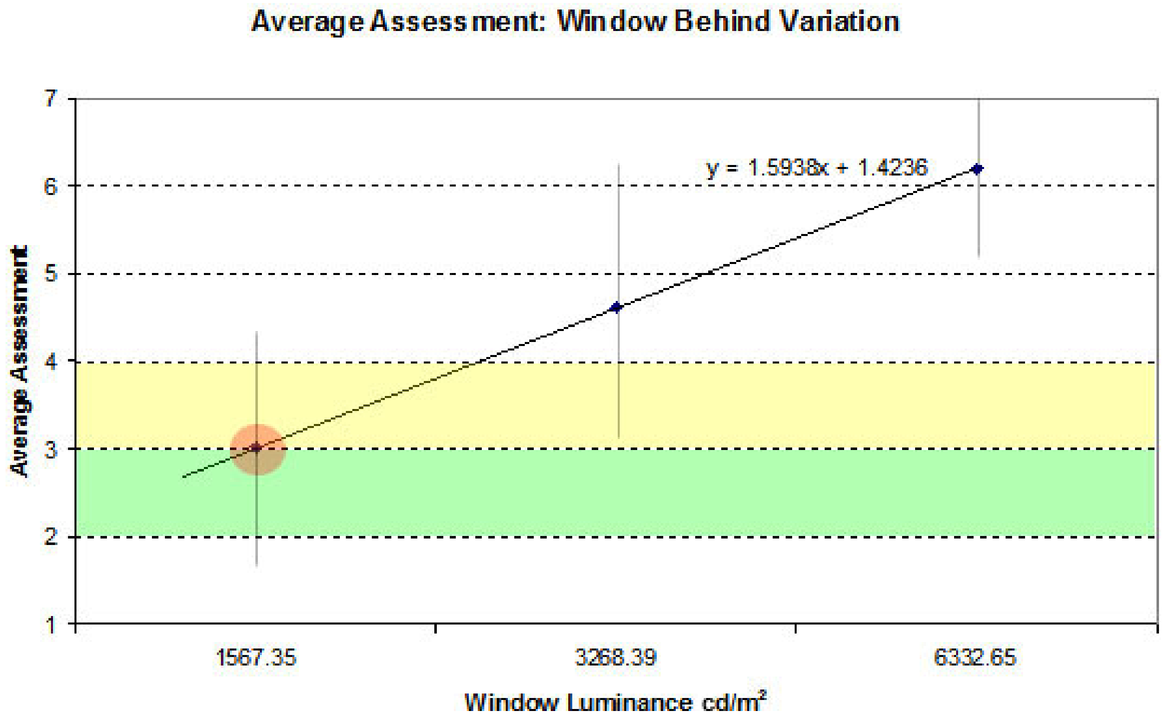


Figure 3.09 Average subjective assessment tests 7 – 9 (window behind variation) trend line with S.D (grey lines) and BCD (red circle) identified

Tests 7 and 8	Tests 8 and 9	Overall position
Appraisal + 1.6	Appraisal + 1.6	Appraisal + 1.6
Tests 7 → 8	**Tests 8 → 9**	
+ 52.3%	+ 105.6%	

Table 3.10 Actual and percentage increases in subjective assessment between the different tests – Window behind variation

The border line of comfort and discomfort (BCD) when the window was behind the user was:

- Window luminance of 1550.24 cd/m^2
- Window to task area ratio of 10.44:1

In this position since the window is nowhere in the field of view (see figure 3.10 for luminances in field of view for this position), it is prudent to use the ratio between the walls and the adaptation luminance instead of that between the window and adaptation luminance (although this is documented for continuity).

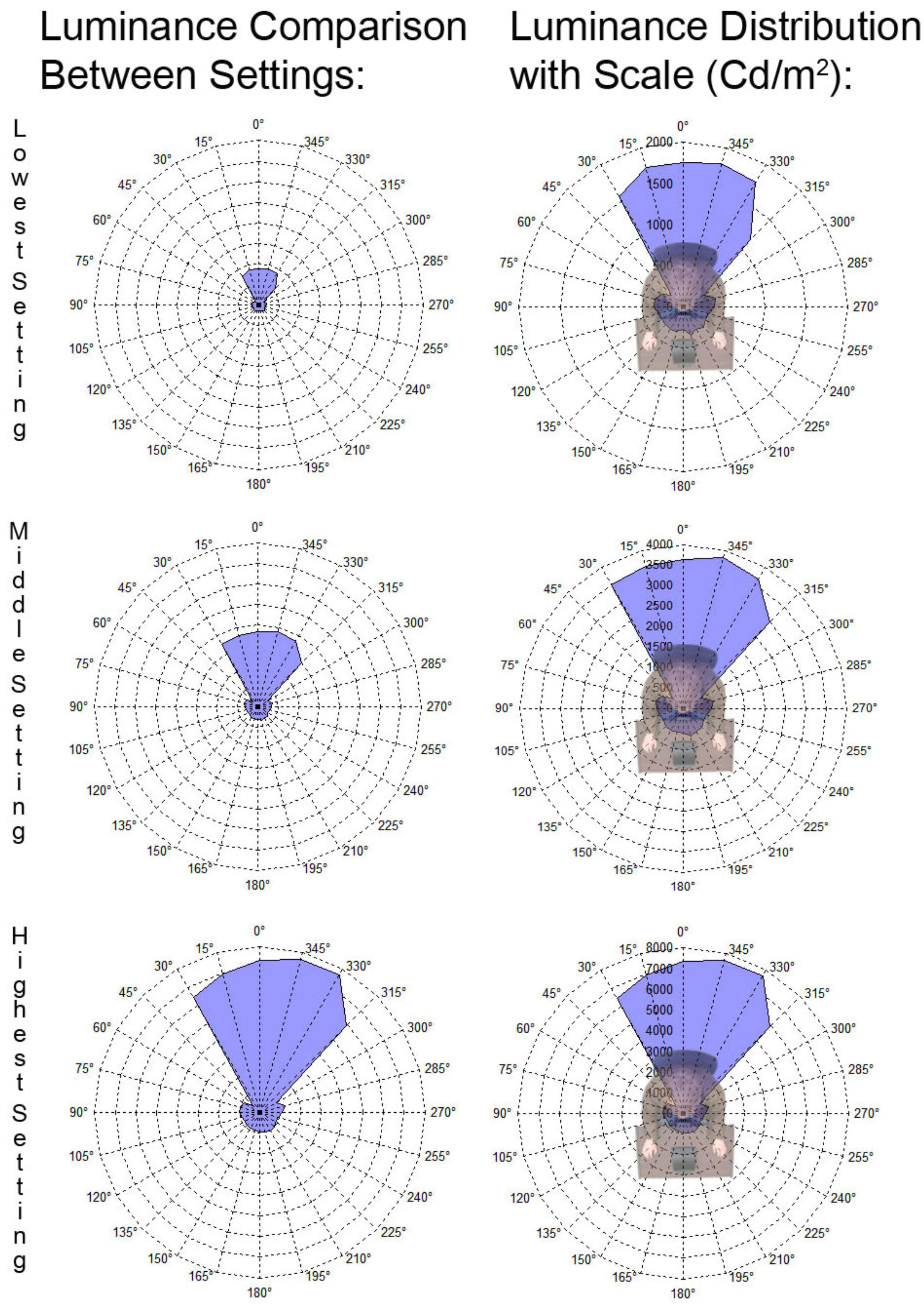


Figure 3.10 Field of view (and comparison of) luminance values at eye height for each window luminance setting when the window is behind user

The approximate adaptation luminance is 255.38 cd/m^2. The type of ratios and percentage difference in these that could be expected at the BCD luminance for this position (calculations for all these can be found in appendix one – assumes same window layout) are:

- 6.07:1 (window to adaptation luminance – unlikely to have a noticeable impact on comfort levels since the window is not within the field of view)
- 1.72:1 (adaptation to task area luminance)
- 1.16:1 (wall to adaptation luminance)

This represents a percentage difference in the latter two ratios of 48.3% (the percentage difference between the former two is much larger – 252.9% but as this is not in the field of view it is unlikely this affects visual comfort – this is illustrated in figure 3.10). If a link between this difference and subjective assessment does exist and because this layout would likely not mitigate glare effects (according to Occupational Health and Safety (1993) recommendations) then the results here also suggest that larger percentage differences between the adaptation ratios results in lower overall visual comfort (even if one of the ratios is similar to a ratio(s) from a 'good' lighting layout). So it may not be the ratios themselves but rather the percentage difference in the ratios (up to a given BCD glare source luminance threshold) which determines likely visual comfort levels in daylit spaces (where the window has suitably large effects on adaptation levels in the room).

4.0 Visual Test Results and Discussion

Because of the large standard deviations and inconsistencies associated with subjective appraisal of glare, sometimes a more objective measure (i.e. a visual test of the same intrinsic difficulty regardless of who performs it) can help identify whether a particular luminance distribution is actually detrimentally glaring. Although we do not suggest that visual comfort is not important in the consideration of glare, visual tests allow an analysis of the impact on productivity (which often affects economic factors and user piece-of-mind). In this way, the impact on visual comfort and productivity can be weighed against each other to try and find a suitable balance. Also as a by-product of trying to provide environments which do not negatively affect productivity (due to glare), users may actually be more visually comfortable with the environment (those possible links are discussed in section 5.0). As aforementioned, 'productivity' in this experiment refers specifically to errors and duration from a Landolt ring and reading based test (so its applicability to non-VDU work stations or studios is unknown). An 'error' had two definitions based on which section of the test it occurred in:

1 – Users did not find the slit on the Landolt ring within the allotted time frame of 4 seconds or
2 – Users did not count the correct number of the letter they were asked to find from the reading test in which case the error is the average distance from the correct value for that test.

4.1 Test Results Front (Window in front of User)

This section discusses tests 1 – 3 with the window directly in front of the users' field of view (the averages from the other positions are shown in grey solely as a basis for comparison).

4.1.1 Errors

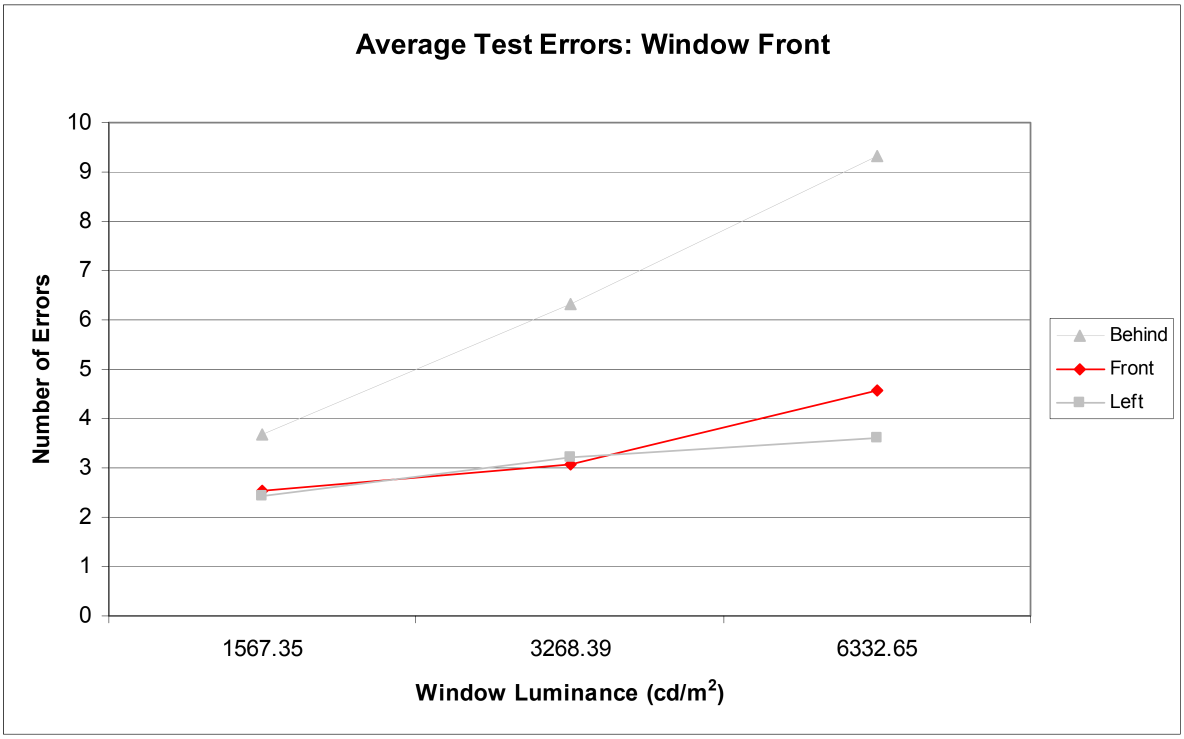


Figure 4.01 Average number of Landolt rings test errors – Tests 1 – 3 (window front variation) in red

The average error rate for the Landolt ring portion of the test in the front variation was similar to that of the left variation for the lower and middle order window luminances although it rose more steeply after this than the other variation. The average error rate was lower than the behind variation across all the window luminances. In the first instance what this suggests is that not only is having the window directly in front of a user's field of view less detrimental to productivity than having the window behind but also that at luminances up to 3268.39 cd/m^2 at least, the impact on productivity is similar to the recommended layout (left variation).

Therefore if the window luminance is not likely to ever exceed this threshold (for any number of reasons such as exterior obstructions, climate or limited visible sky) then setting up a VDU in this position is permissible (or at least the decline in accuracy is similar to that of the recommended layout) so long as visual comfort considerations have been taken into account. If window luminances are likely to exceed this threshold (which in most circumstances will be the case) then it is a weigh up of exterior view (which would be an individual by individual preference), visual comfort and any productivity quotas which could be affected. Overall (specifically from an accuracy stand point), as the front position does not directly cause veiling reflections it would be acceptable to set up this layout (assuming suitably sized windows to set adaptation levels) providing window luminances do not exceed approximately 3270 cd/m2 (further testing of luminance ratios could refine this figure).

Below is the average increase in errors between tests and for the overall position. As each test roughly doubles the window's luminance it should be noted that while the increase between the middle and highest order tests is almost three times as high as the increase between the lowest and middle order tests, the former represents an increase in average window luminance of 1700 cd/m2 whilst the latter is 3064 cd/m2 (almost twice the increase). Still, the increase in luminance is by a factor of approximately 2 while the increase in error rate is by a factor of almost 3.

Tests 1 → 2	**Tests 2 → 3**	**Average Between Tests**
+ 0.5425	+1.5205	+1.03
Tests 1 → 2	**Tests 1 → 3**	
+ 21.5%	+ 81.8%	

Table 4.01 Actual and percentage increases in number of Landolt ring errors – Window front variation

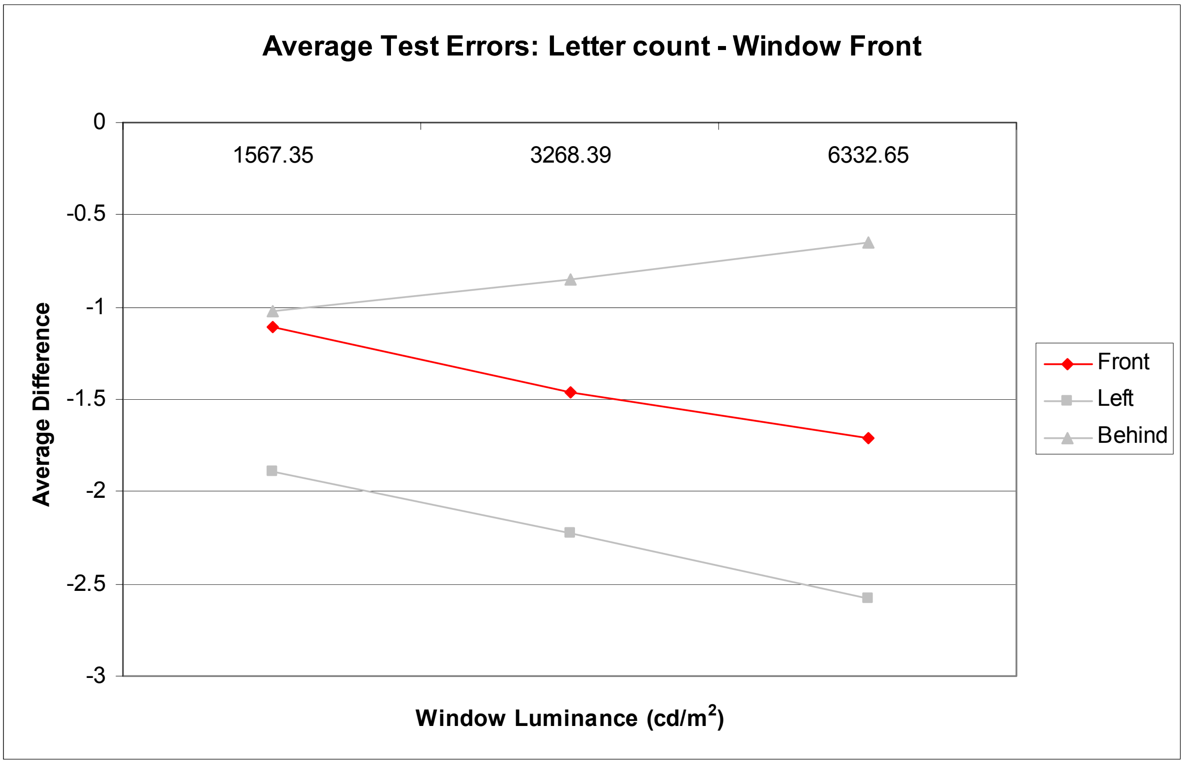


Figure 4.02 Average number of letter count test errors – Tests 1 – 3 (window front variation) in red

For the letter count portion, the error rate for the front variation was lower than the left variation by almost half but higher than the behind variation. The fact that in this front position, the accuracy was higher than the recommended left variation poses an interesting issue. It suggests that up to a window luminance of at least 6300 cd/m2, having no direct light from a window source reflecting off the screen aids accuracy for reading text based tasks (at least in comparison to having a perpendicular window source). Curiously also, the rate of decline in productivity fell when the lower/middle order is compared to the middle/higher order test suggesting that the while visual comfort decreases more rapidly as window luminance increased, the rate at which this facet of productivity declines actually falls after a certain luminance threshold is passed.

Tests 1 → 2	Tests 2 → 3	Average Between Tests
+ 0.36	+ 0.25	+ 0.3
Tests 1 → 2	**Tests 1 → 3**	
+ 32.1%	+ 54.7%	

Table 4.02 Actual and percentage increases in number of letter count errors – Window front variation

4.1.2 Duration

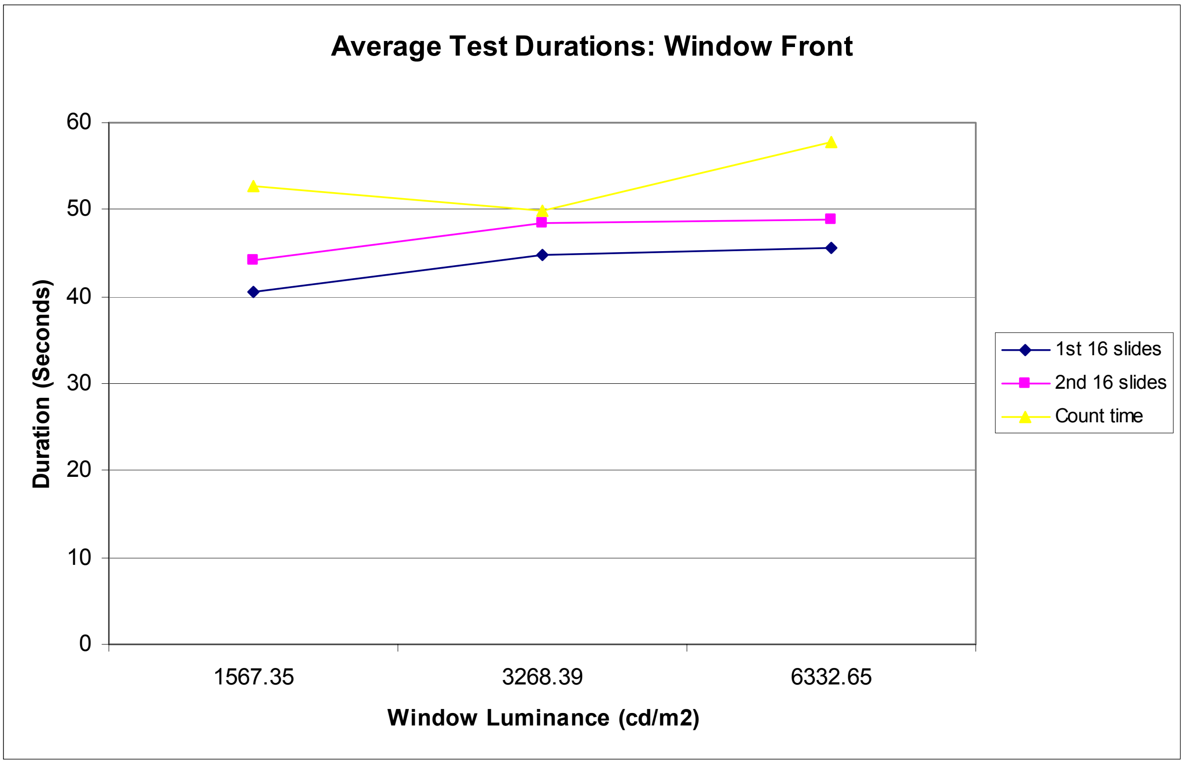


Figure 4.03 Average visual test durations – Tests 1 – 3 (window front variation)

The durations for the first and second half of the Landolt ring portion of the test both showed larger increases in duration between the lowest and middle order tests than the middle and highest order. This suggests that once a certain luminance threshold (approximately 3268 cd/m2 in this particular test) is crossed, the rate at which the duration increases will decrease. The average duration for the first 16 slides is also lower across all luminances than the second 16. If the impact of learning was not factored out (see section 2.7.1) then this would have meant users would become more efficient at the test and therefore have a lower overall duration for the second 16 slides than the first 16 (which was not the case in any of these variations). What the results do suggest is that continued exposure to the same luminance (not necessarily increasing luminance) will reduce efficiency overtime even if the intrinsic difficulty of the task is unchanged. The duration for the letter count portion of the test actually reduced between test 1 and 2 although between tests 2 and 3 plus overall, showed a strong increase. As the room was illuminated to recommended levels prior to the window being turned on it is difficult to explain why duration decreased between tests 1 and 2 although it may simply be that at the window luminances tested, the glare is not strong enough to have a direct impact on count times (although this is very unlikely given the corresponding comfort level declinations (see section 3.1) and other objective measures at these luminance levels). Below are the increases/decreases in test durations between tests and overall plus the differences in duration between the 1st and 2nd 16 Landolt ring slides:

	Tests 1 → 2	**Tests 2 → 3**	**Average Between Tests**
1st 16 Landolt rings	+ 4.3	+ 0.7	+ 2.5
2nd 16 Landolt rings	+ 4.2	+ 0.35	+ 2.3
Letter Count Slide	- 2.7	+ 7.8	+ 2.6
	Tests 1 → 2	**Tests 1 → 3**	
1st 16 Landolt rings	+ 10.6%	+ 12.4%	
2nd 16 Landolt rings	+ 9.5%	+ 10.5%	
Letter Count Slide	- 5.1%	+ 9.8%	

Table 4.03 Actual and percentage increases in visual test duration – Window front variation

4.1.3 Screen Contrasts and Ratios

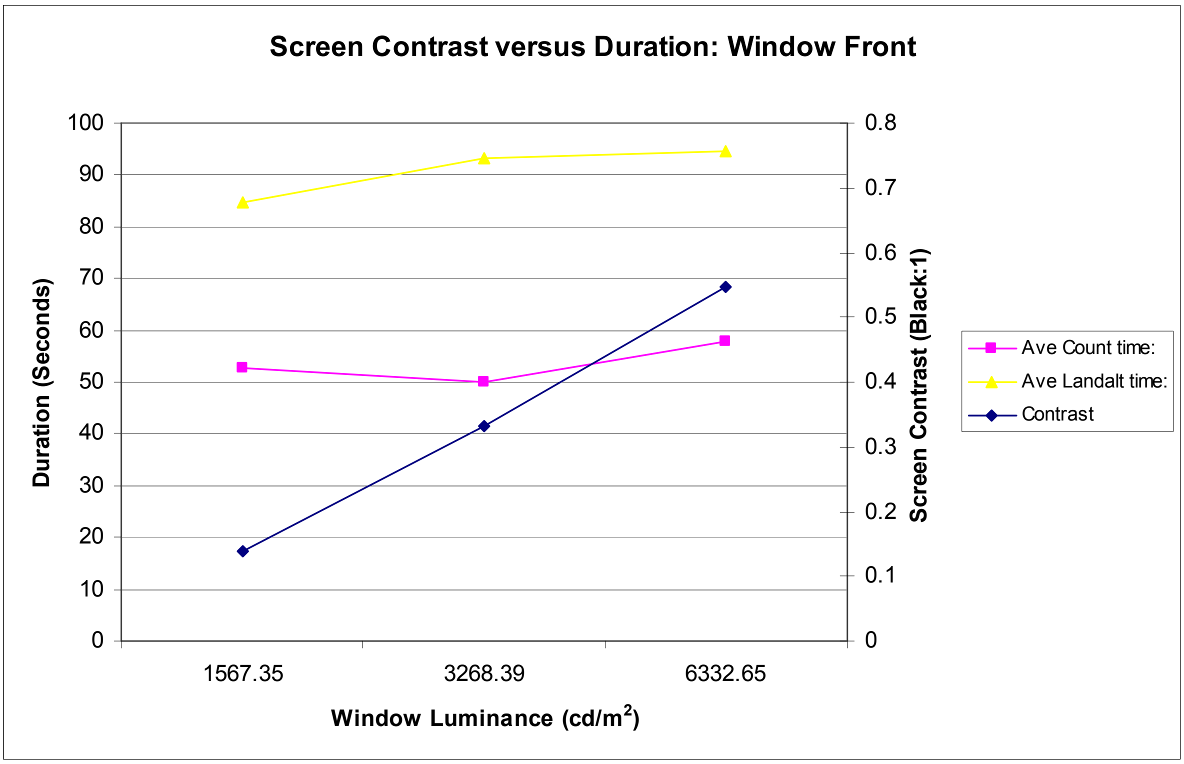


Figure 4.04 Average visual test durations versus Laptop screen contrast (white:black) – Tests 1 – 3 (window front variation)

Contrast is an important consideration when dealing with visual tasks (see section 5.0). The contrast within the task area (i.e. on the screen) is the ratio of the luminance of a white part of the screen to the luminance of a black part of the screen (e.g. black text on white background) as seen from the user's viewpoint. In the case of the front variation, the screen contrast reduces as window luminance increased by saturating the screen with light reflected of wall surfaces. This suggests an inverse relationship between screen contrast and test duration (which intuitively we know to make sense). In the case of a laptop screen, it is unlikely it would ever become a glare source itself due to too high a contrast as the luminance never rose above approximately 135 cd/m^2. If there is any link between test duration and screen contrast the results suggest that a relatively large shift in screen contrast will result in a relatively small increase in duration (see table below):

	Tests 1 → 2	**Tests 2 → 3**
% Increase in Landolt ring time	+ 10%	+ 1%
% Increase in counting time	- 5.1%	+ 16%
% Reduction in contrast	137.4%	67%
	Tests 1 → 2	**Tests 1 → 3**
% Increase in Landolt ring time	+ 10%	+ 11.4%
% Increase in counting time	- 5.1%	+ 9.8%
% Reduction in contrast	137.4%	294.2%

Table 4.04 Percentage increases in visual test duration VS Percentage decreases in screen contrast – Window front variation

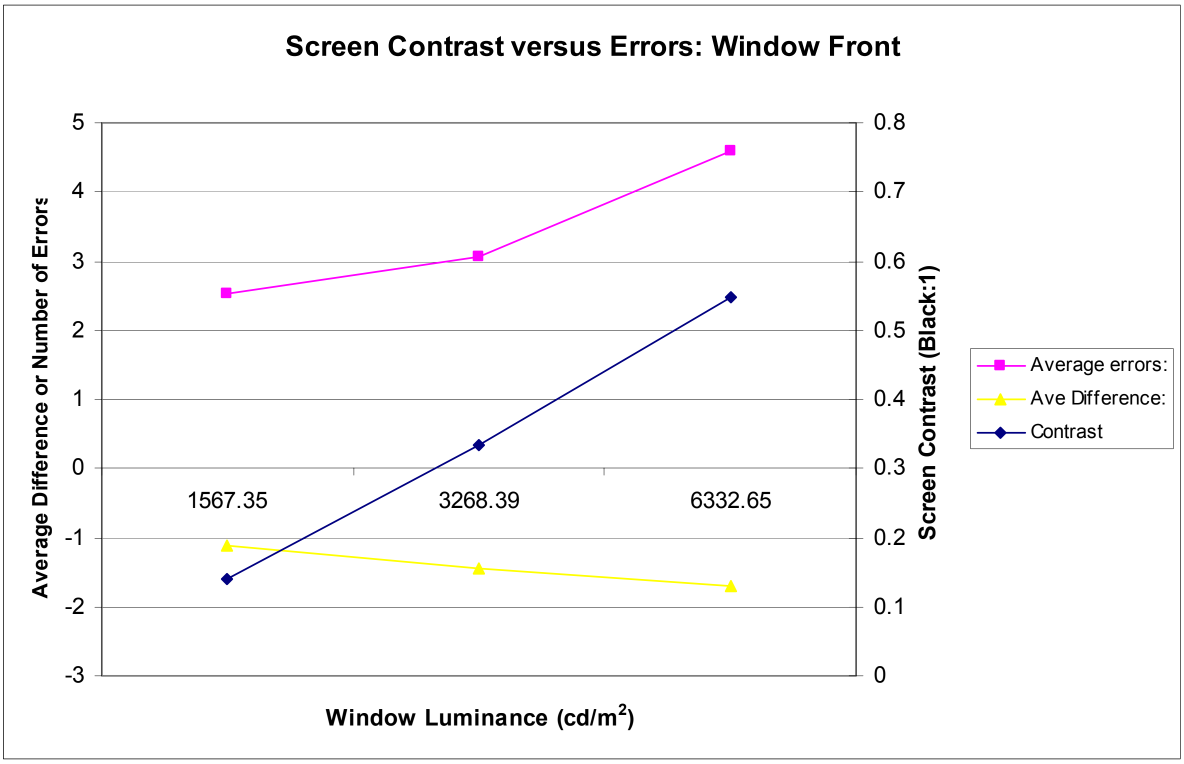


Figure 4.05 Average visual test errors versus Laptop screen contrast (white:black) – Tests 1 – 3 (window front variation)

A reduction in screen contrast could also have a detrimental effect on the error rates from the visual test. Both the number of Landolt ring errors and the accuracy from the letter count portion display an increase as contrast reduced. The percentage increase in Landolt ring errors was closer to the percentage reduction in contrast than the duration results suggesting that users require only a small increase in the time to perform the test but that errors are more highly impacted upon at any rate.

	Tests 1 → 2	Tests 2 → 3
% Increase in Landolt ring errors	+ 21.5%	+ 49.7%
% Increase in letter counting errors	+ 32.1%	+ 17.1%
% Reduction in contrast	137.4%	67%
	Tests 1 → 2	**Tests 1 → 3**
% Increase in Landolt ring errors	+ 21.5%	+ 81.8%
% Increase in letter counting errors	+ 32.1%	+ 54.7%
% Reduction in contrast	137.4%	294.2%

Table 4.05 Percentage increases in visual test errors VS Percentage decreases in screen contrast – Window front variation

4.2 Test Results Side (Window 90° from User FOV)

This section discusses tests 4 – 6 with the window 90° from the centre of the users' field of view (the averages from the other positions are shown in grey solely as a basis for comparison).

4.2.1 Errors

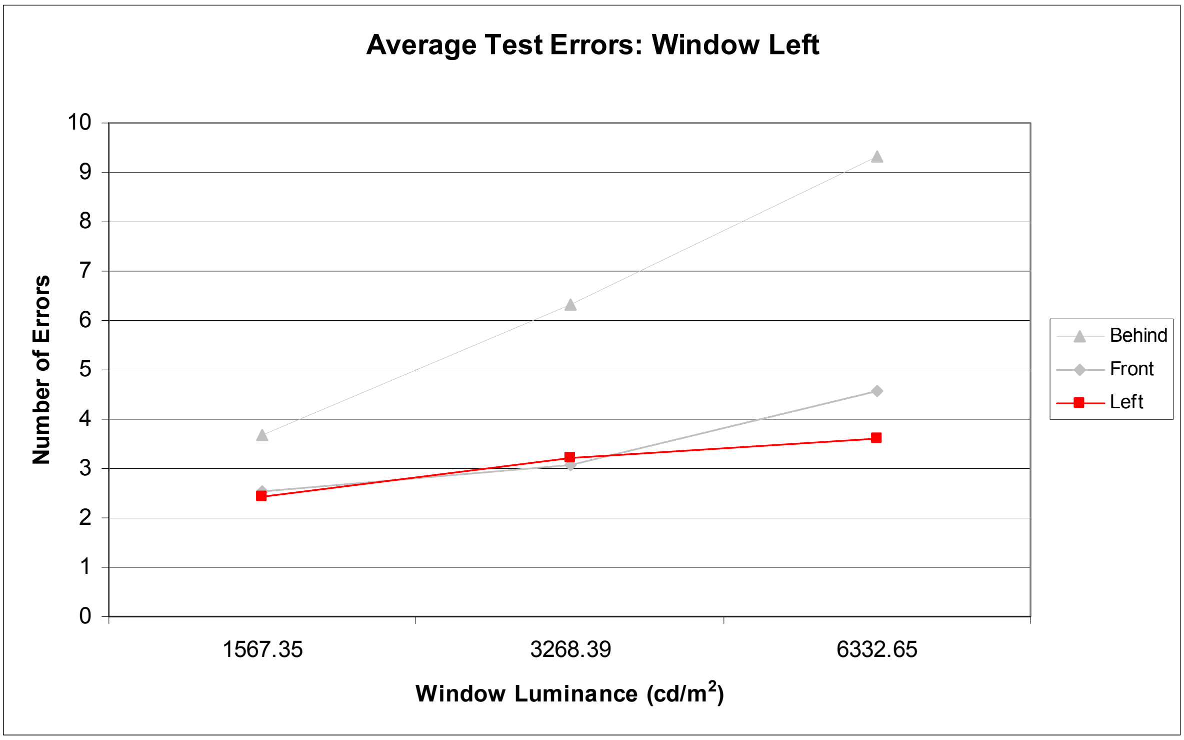


Figure 4.06 Average number of Landolt rings test errors – Tests 4 – 6 (window left variation) in red

As previously mentioned, the average number of errors in the Landolt ring portion of the test was very similar between the lowest and middle order window luminances. However at the middle and highest order window luminances the error rate not only becomes noticeably lower than both the front and behind variations but the rate at which the error rate increases actually declines. As most daylit installations will have window luminances exceeding 3270 cd/m^2, positioning VDU workstations perpendicular to windows rather than directly in front of would be justified to reduce the rate at which accuracy declines.

Tests 4 → 5	Tests 5 → 6	Average Between Tests
+ 0.7708	+ 0.396	+ 0.583
Tests 4 → 5	**Tests 4 → 6**	
+ 31.6%	+ 47.9%	

Table 4.06 Actual and percentage increases in number of Landolt ring errors – Window left variation

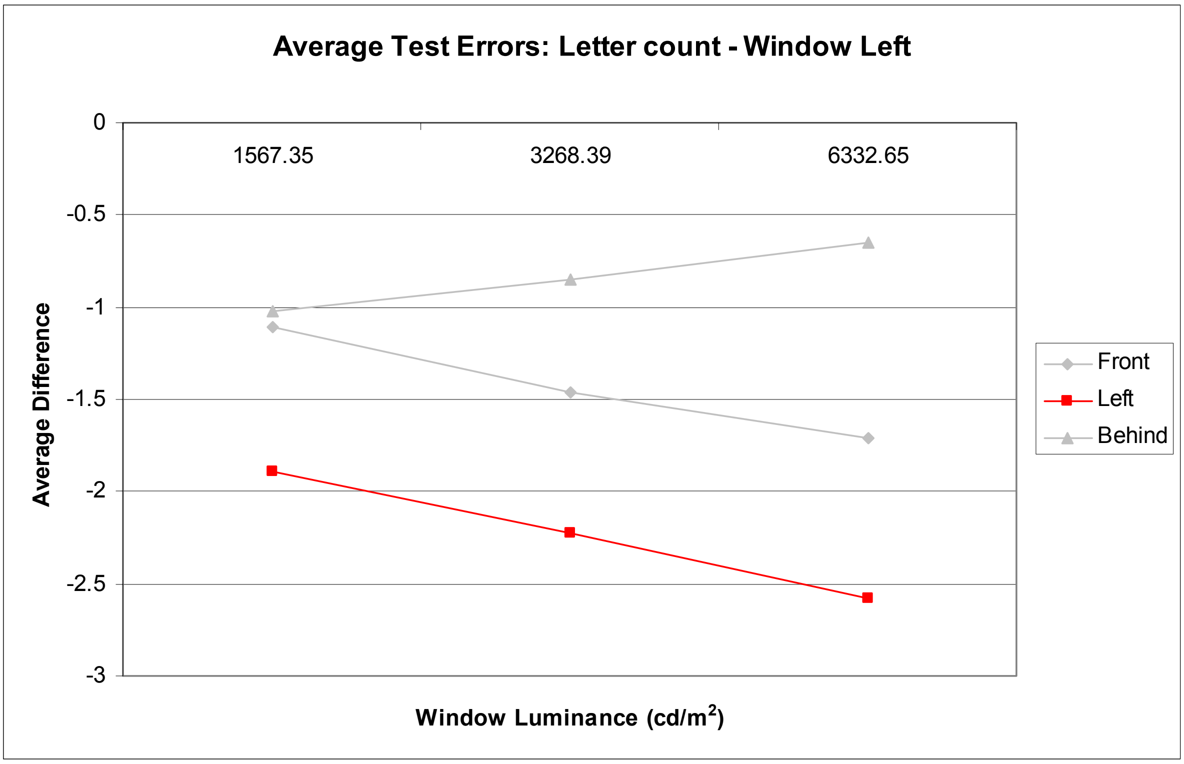


Figure 4.07 Average number of letter count test errors – Tests 4 – 6 (window left variation) in red

The average error rate for the counting section of the test was actually the highest for the left position which appears at odds with recommendations for daylit office layouts. Although the decline in accuracy is similar to that of the front variation, the initial handicap to users from the window luminance is such that the overall error rate is noticeably higher (although this trend is only tied to reading text based tasks not simple scanning tasks like the Landolt ring portion of the test). A possible reason for these results is that when it comes to reading, the eyes require a reasonably uniform luminance across the field of view and having a peripheral window glare source causes a sufficient variation in screen contrast and glare sensation across the field of view to inhibit character recognition on the fly. In the other two positions although they may cause more severe visual discomfort, the effect is uniform across the field of view. Below are the increases in errors between tests and overall:

Tests 4 → 5	Tests 5 → 6	Average Between Tests
+ 0.34	+ 0.35	+ 0.345
Tests 4 → 5	**Tests 4 → 6**	
+ 17.6%	+36.2%	

Table 4.07 Actual and percentage increases in number of letter count errors – Window left variation

4.2.2 Duration

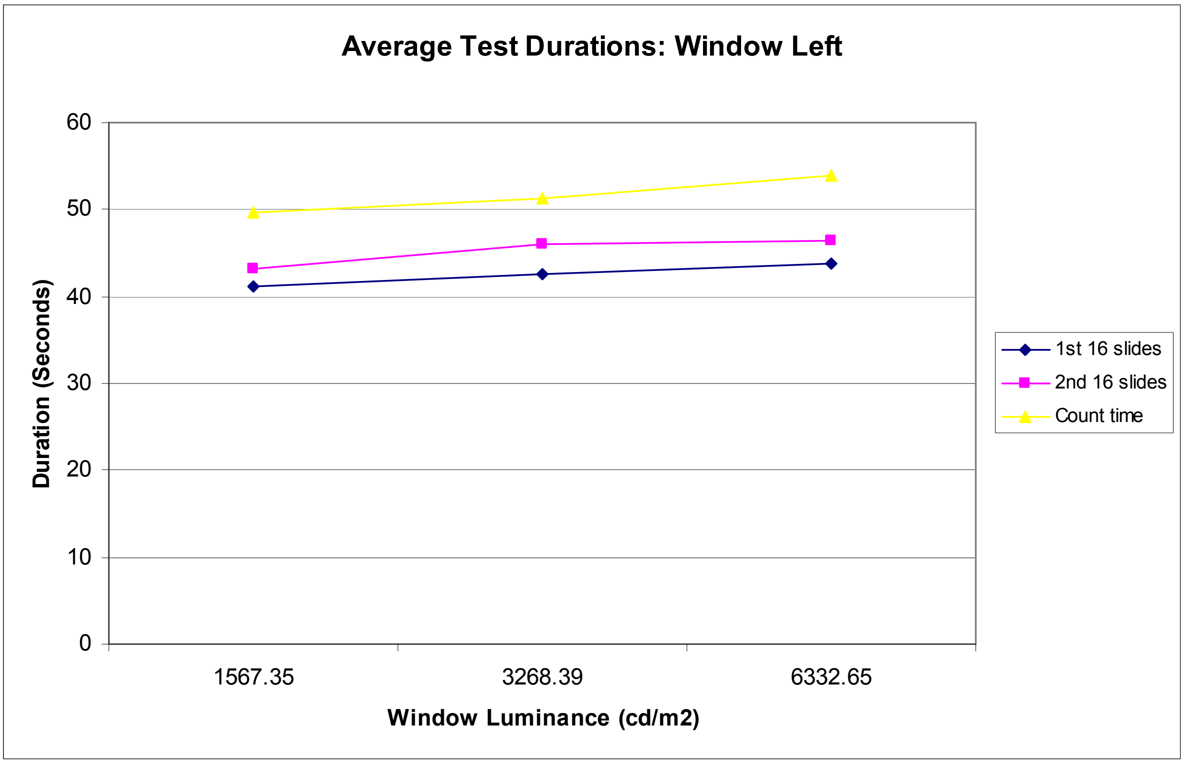


Figure 4.08 Average visual test durations – Tests 4 – 6 (window left variation)

The durations for the 1st and 2nd 16 Landolt ring slides displayed slight differences in the test durations between the lowest and middle order luminance tests and the middle and highest luminance order tests. However these changes are smaller than the front variation suggesting a perpendicular window source will result in only a small increase in the rate of productivity decline regardless of the window luminance (at least up to a window luminance of approximately 6300 cd/m^2). The increase in the rate of duration between the lower/middle order and middle/higher order tests for the counting portion of the test increases although was observed in the front variation but in left variation the increase is much less. The time for the first 16 Landolt ring slides was lower than the test times for the latter 16 at all window luminances. Again the results suggest that regardless of the actual luminance of the window, productivity levels (duration) will decline with continued exposure to the same conditions. The increase in duration was less at the lowest luminance ratio (the actual differences are listed below).

	Tests 4 and 5	Tests 5 and 6	Average Between Tests
1st 16 Landolt rings	+ 1.5	+ 1.2	+ 1.3
2nd 16 Landolt rings	+ 2.9	+ 0.4	+ 1.6
Letter Count Slide	+ 1.8	+ 2.5	+ 2.1
	Tests 4 → 5	**Tests 4 → 6**	
1st 16 Landolt rings	+ 3.4%	+ 6.4%	
2nd 16 Landolt rings	+ 6.6%	+ 7.5%	
Letter Count Slide	+ 3.5%	+ 8.6%	

Table 4.08 Actual and percentage increases in visual test duration – Window left variation

4.2.3 Screen Contrasts and Ratios

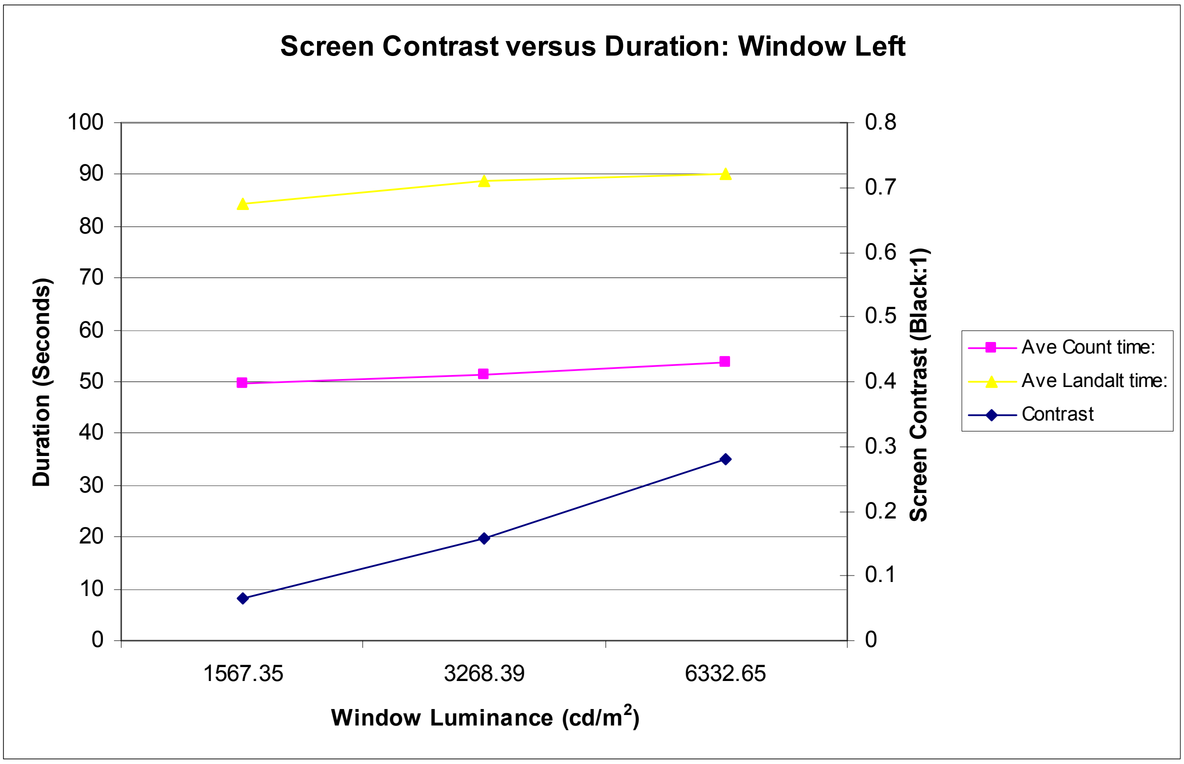


Figure 4.09 Average visual test durations VS Laptop screen contrast (white:black) – Tests 4 – 6 (window left variation)

The contrast levels on the laptop screen were higher in this position than the others (see section 5.0 for discussion regarding these levels). The contrast reduction between each window luminance is reduced in this position and the corresponding increases in test durations have also reduced.

	Tests 4 → 5	Tests 5 → 6
% Increase in Landolt ring time	+ 5.1 %	+ 1.7%
% Increase in counting time	+ 3.5%	4.9%
% Reduction in contrast	135%	78.9%
	Tests 4 → 5	**Tests 4 → 6**
% Increase in Landolt ring time	+ 5.1 %	+ 6.9%
% Increase in counting time	+ 3.5%	+ 8.6%
% Reduction in contrast	135%	320%

Table 4.09 Percentage increases in visual test duration VS Percentage decreases in screen contrast – Window left variation

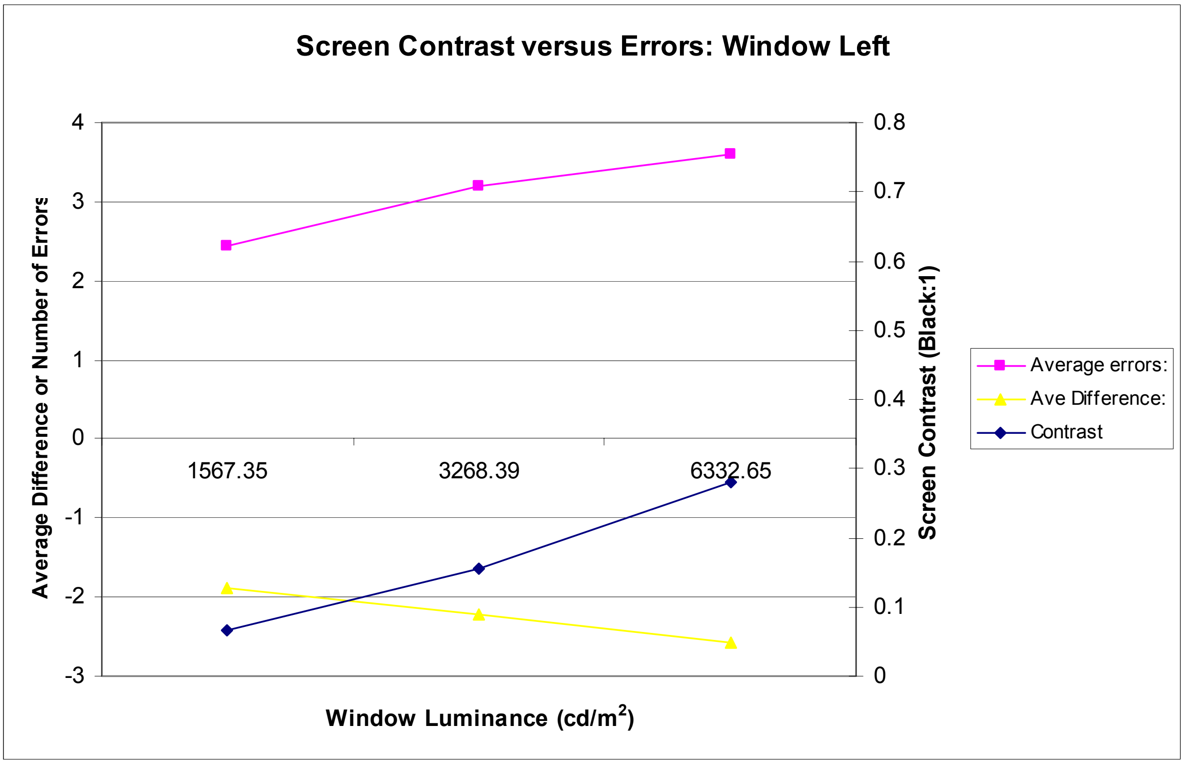


Figure 4.10 Average visual test errors VS Laptop screen contrast (white:black) – Tests 4 – 6 (window left variation)

The relationship between the screen contrast and the error rates is similar for the left variation as for the front. Both the number of errors from the Landolt ring portion of the test and overall deviation from the correct response in the letter count portion increased as screen contrast reduced.

	Tests 4 → 5	Tests 5 → 6
% Increase in Landolt ring errors	+ 31.6%	+ 12.5%
% Increase in letter counting errors	+ 17.6%	+ 15.7%
% Reduction in contrast	135%	78.9%
	Tests 4 → 5	**Tests 4 → 6**
% Increase in Landolt ring errors	+ 31.6%	+ 47.9%
% Increase in letter counting errors	+ 17.6%	+ 36.2%
% Reduction in contrast	135%	320%

Table 4.10 Percentage increases in visual test errors VS Percentage decreases in screen contrast – Window left variation

4.3 Test Results Behind (Window Behind User)

This section discusses tests 7 – 9 with the window 180° (i.e. behind the user) from the centre of the users' field of view (the averages from the other positions are shown in grey solely as a basis for comparison).

4.3.1 Errors

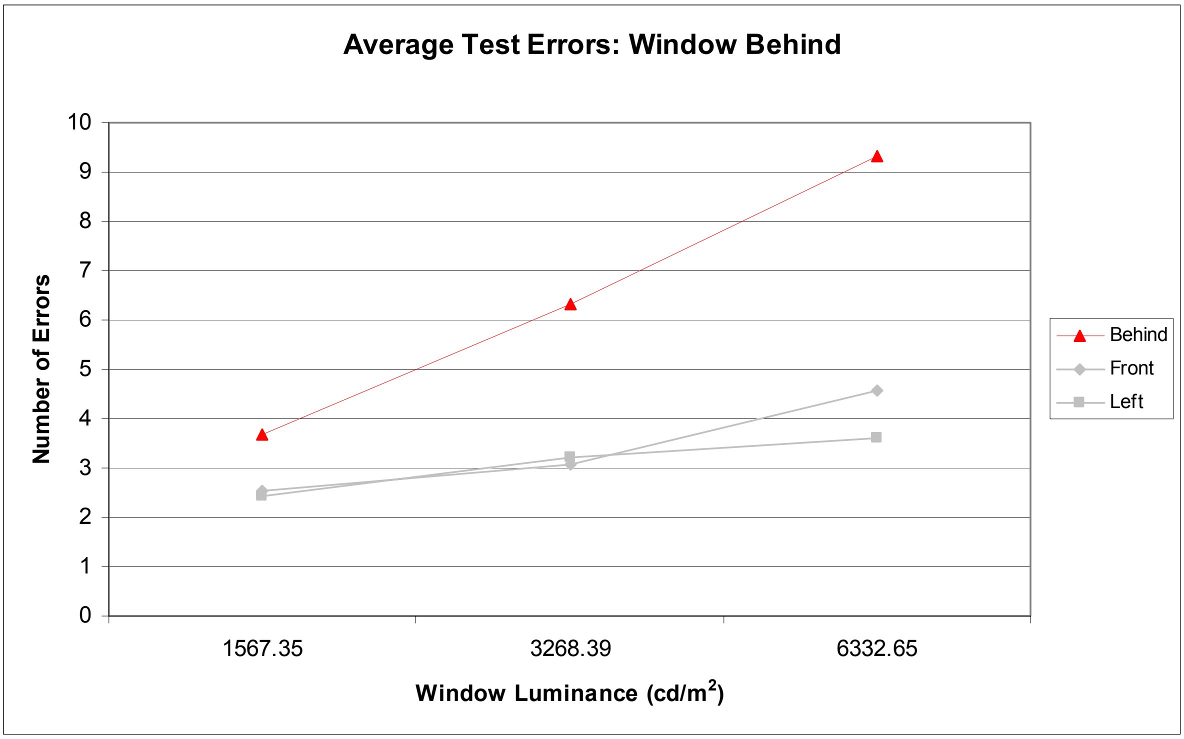


Figure 4.11 Average number of Landolt rings test errors – Tests 7 – 9 (window behind variation) in red

The average test errors in the behind variation was much higher than in this position than either the front or left variations across all the window luminances which were tested. The rate at which the number of errors increases in this position was reasonably consistent in comparison to the others, which could be due to the fact that in this position no direct light from the window is visible and the general inclination in room brightness is more diffuse. Despite the consistent rate of increase in errors, the rate itself is higher than that of the other positions plus the initial error level is much higher suggesting that having windows outside of the field of view but behind the user to illuminate their workstation results in a very negative effect on accuracy in comparison to other layouts. At the highest window luminance, the average number of Landolt ring test errors was between 100 and 140% greater than the other positions. The error rate between each window luminance is listed below:

Tests 7 → 8	Tests 8 → 9	Average Between Tests
+ 2.7	+ 3.0	+ 2.8
Tests 7 → 8	**Tests 7 → 9**	
+ 72.7%	+ 154.0%	

Table 4.11 Actual and percentage increases in number of Landolt ring errors – Window behind variation

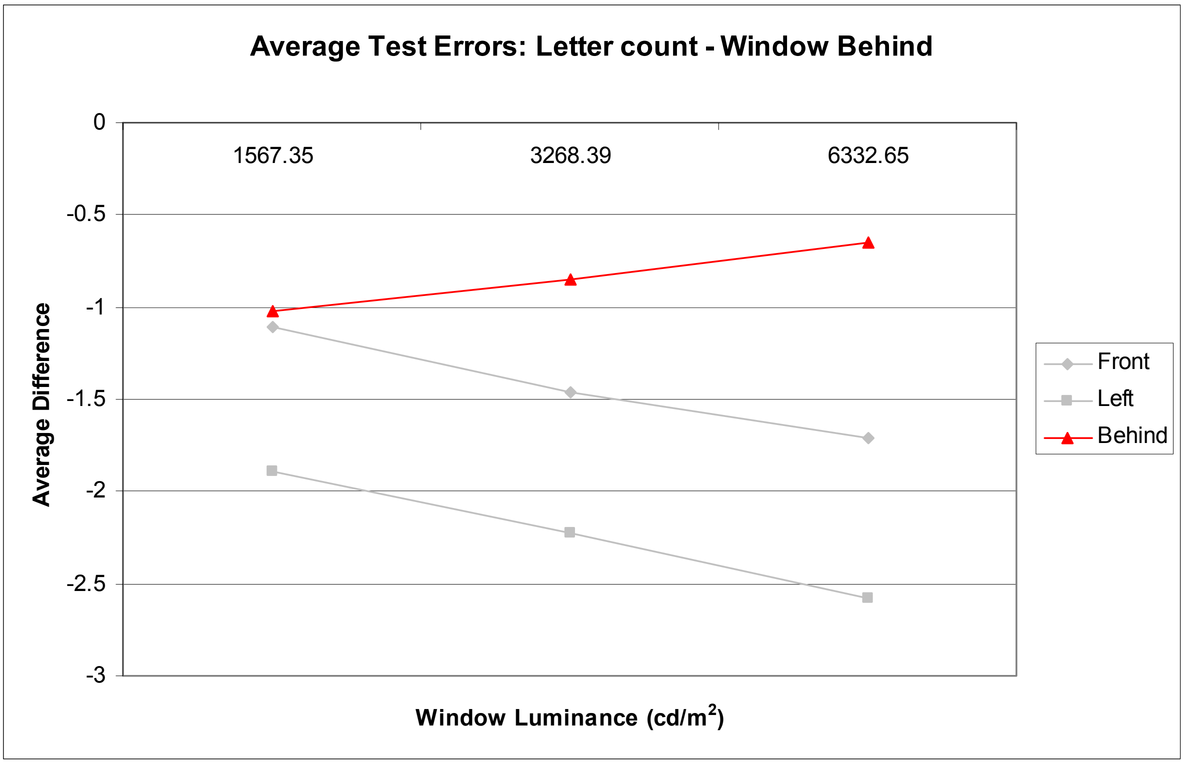


Figure 4.12 Average number of letter count test errors – Tests 7 – 9 (window behind variation) in red

Oddly, the overall accuracy of the letter count increased as the window luminance was increased. This is not only at odds with the other objective results but also the overall subjective appraisals of the lighting conditions presented in this layout. The possibility exists that the results from this part of the visual test are not actually tied to the lighting quality presented at the time but rather the intrinsic difficulty of the letter count itself. Subjects were required to look for the letter 'W'. Although it is very difficult to verify, the possibility exists that a 'W' is simply intrinsically easy to identify amongst other letters due to its size or shape than an 'N' or an 'R' which were used in the other positions. Of course it is possible that the lighting conditions contributed to the increased overall accuracy but because of the other objective and subjective results this seems unlikely (this is discussed further in section 7.0).

Tests 1 → 2	Tests 2 → 3	Average Between Tests
- 0.17	- 0.21	- 0.188
Tests 1 → 2	**Tests 1 → 3**	
- 16.3%	- 36.7%	

Table 4.12 Actual and percentage increases in number of letter count errors – Window behind variation

4.3.2 Duration

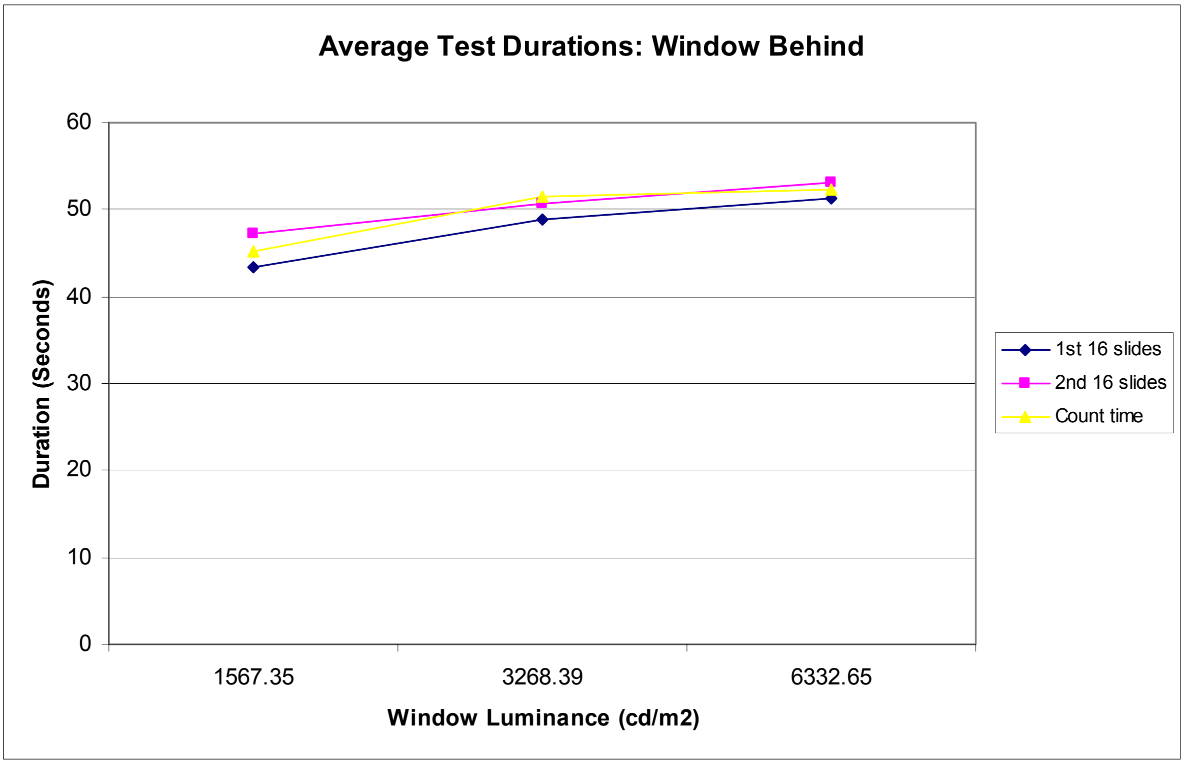


Figure 4.13 Average visual test durations – Tests 7 – 9 (window behind variation)

Like many of the test durations from the other layouts, the rate of increase in test duration for the Landolt ring portion began to decline after the middle order window luminance. This trend extends to the counting time in this position also. Again this supports the idea of a luminance threshold after which the impact on productivity (for duration only) will begin to decline. This is due possibly to some type of luminance saturation point - after which the luminance is sufficient that an increase of even an order of two (as in this case although still negatively impacting productivity) is proportionately less detrimental. Further study would be required to identify such daylight luminance thresholds. Once again, the average duration for the 1st 16 Landolt ring slides is less than the 2nd 16 slides reaffirming the notion that if learning is factored out, a constant window luminance (even a relatively low one) will reduce task efficiency over time (although if the idea of a luminance threshold is in fact true then this difference would reduce at higher window luminances).

	Tests 7 and 8	Tests 8 and 9	Average Between Tests
1st 16 Landolt rings	+ 5.5	+ 2.4	+ 3.9
2nd 16 Landolt rings	+ 3.4	+ 2.6	+ 3.0
Letter Count Slide	+ 6.4	+ 0.8	+ 3.6
	Tests 7 → 8	**Tests 7 → 9**	
1st 16 Landolt rings	+ 12.7%	+ 18.2%	
2nd 16 Landolt rings	+ 7.3%	+ 12.9%	
Letter Count Slide	+ 14.1%	+ 15.9%	

Table 4.13 Actual and percentage increases in visual test duration – Window behind variation

4.3.3 Screen Contrasts and Ratios

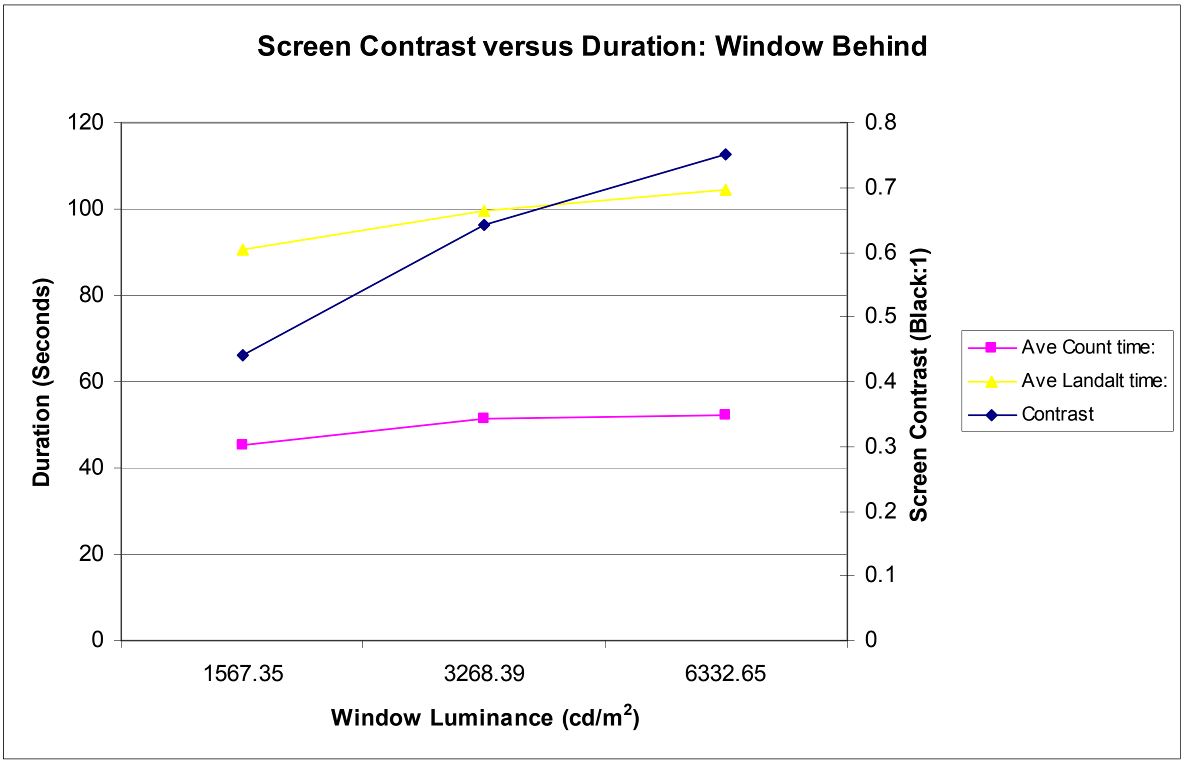


Figure 4.14 Average visual test durations VS Laptop screen contrast (white:black) – Tests 7 – 9 (window behind variation)

The window behind variation produced some of the lowest screen contrasts; clearly due to the fact the window was shining light directly onto the screen. The following are the relative decreases/increases in screen contrast and test durations.

	Tests 7 → 8	**Tests 8 → 9**
% Increase in Landolt ring time	+ 9.8%	+ 5.0%
% Increase in letter counting time	+ 14.1%	+ 1.6%
% Reduction in contrast	46%	17%
	Tests 7 → 8	**Tests 7 → 9**
% Increase in Landolt ring time	+ 9.8%	+ 15.4%
% Increase in letter counting time	+ 14.1%	+ 15.9%
% Reduction in contrast	46%	70%

Table 4.14 Percentage increases in visual test duration VS Percentage decreases in screen contrast – Window behind variation

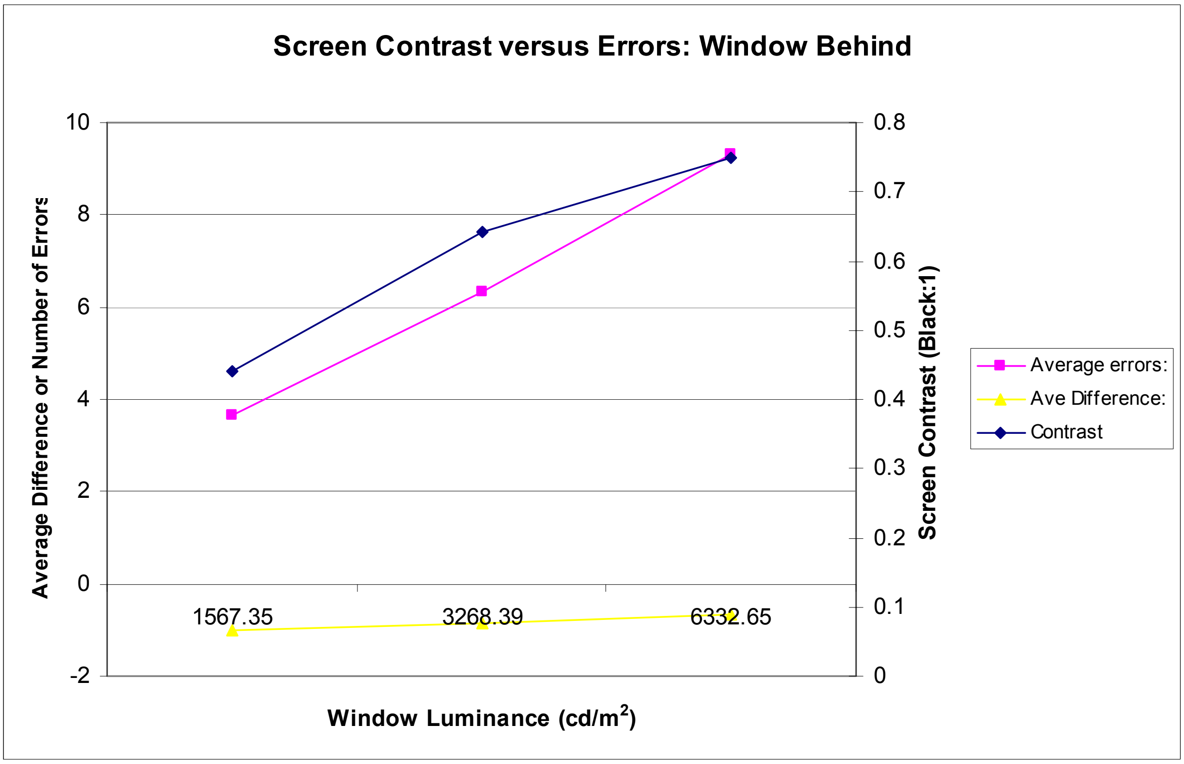


Figure 4.15 Average visual test errors VS Laptop screen contrast (white:black) – Tests 7 – 9 (window behind variation)

While the number of Landolt ring slide errors shows a strong correlation with reducing screen contrast in this position, we see again the intuitively odd results of the letter count portion which illustrated an overall increase in reading comprehension accuracy as the screen contrast reduced. As we know that the Landolt ring portion of the test has the same intrinsic difficulty (because of the nature of the test where users scanned the exact same slides but merely in a different order) showed a distinct reduction in accuracy as the window luminance increased, this (along with the test duration results and subjective appraisals) supports the theory that the letter 'W' is simply an easier letter to find amongst other characters than an 'N' or 'R' so no powerful conclusion regarding reading based errors and window luminance can be found here (see section 7.0 for recommendations regarding further research).

	Tests 7 → 8	Tests 8 → 9
% Increase in Landolt ring errors	+ 72.5%	+ 47.6%
% Increase in letter counting errors	- 16.3%	- 23.5%
% Reduction in contrast	46%	17%
	Tests 7 → 8	**Tests 7 → 9**
% Increase in Landolt ring errors	+ 72.5%	+ 154.0%
% Increase in letter counting errors	- 16.3%	- 36.7%
% Reduction in contrast	46%	70%

Table 4.15 Percentage increases in visual test errors VS Percentage decreases in screen contrast – Window behind variation

5.0 Links between Discomfort Glare Factors and Disability Glare Factors

As previously noted, 'veiling reflections' are typically associated with disability (glare which reduces productivity) which is why the subjective assessment response averages for the 'window behind' variations appear to be at odds with what typical glare definitions stipulate since the high luminance is outside the field of view. Regardless of the luminance ratio being tested, the overall subjective assessment for visual comfort was higher (more disturbing) when the window was behind the users than in any other position. While the test results appear intuitively in line with what literature says should happen (errors, letter count accuracy and test duration were all detrimentally affected as the window luminance was increased and were most negatively affected when the window was behind the user) we are left somewhat at odds with the literature with comfort level assessments for each of the positions. We must therefore try and explain why the layout which presented the highest luminance ratios between task area, window or adaptation level (the 'window front' variation) was assessed as more visually acceptable than the layout which had the lowest ratios between those different visual areas or factors. Boer, (1977) spoke on the impact of veiling reflections (and reductions in screen contrast) on both productivity and comfort and whilst he too defined veiling reflections as being “disturbing due to the resultant decreases in luminance contrast of the task detail” he also went on to say that they can be disturbing to VDU users because of “the glare from the bright veil itself” (p. 74). It is difficult to conclude the various levels of impact of the two glare types on productivity but fair to suggest that productivity is affected by both.

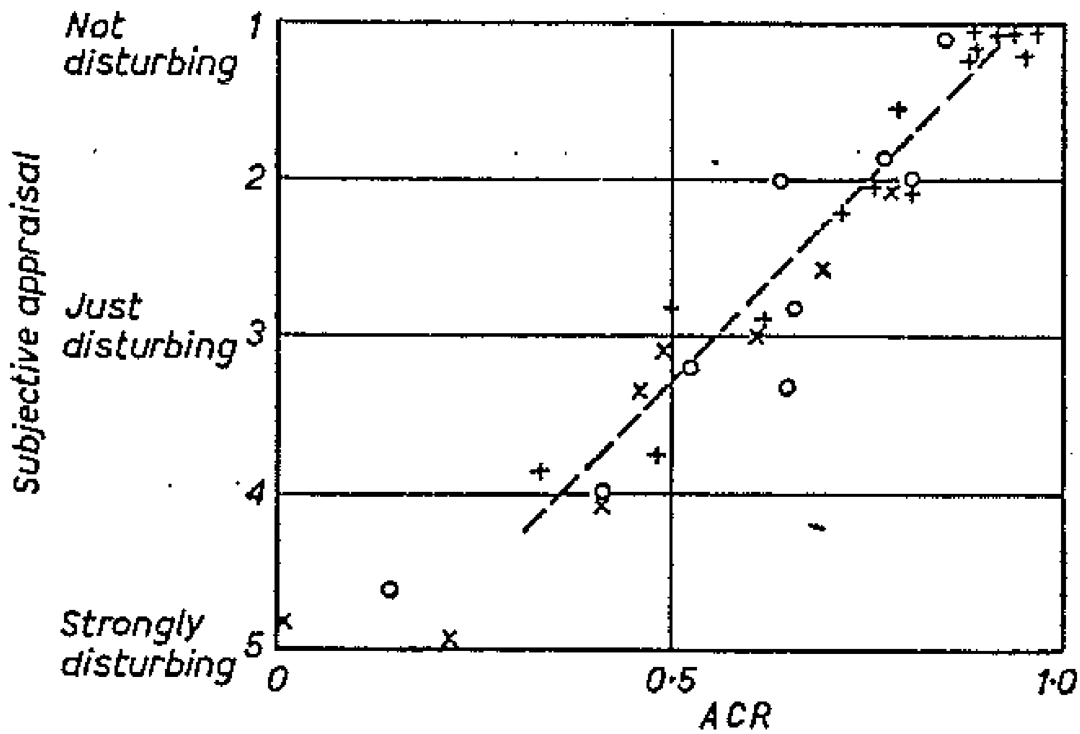


Figure 5.01 Example of research examining links between screen contrast and comfort

This still does not entirely explain the discomfort levels experienced by users as the "bright veil itself" in the case of this experiment was recorded at low luminances (see appendix one) during each of the different window luminances. Angular differences may cause some fluctuations in these readings e.g. differences due to user height, head position etc. None of these comes close to the recommended maximum luminance for comfort threshold of 1500cd/m2 but the definition Boer (1977) puts forward does at least suggest some link between veiling reflections and comfort (rather than just productivity). But the most important effect of veiling reflections has still not been considered i.e. the reduction in contrast in the task area, which will vary depending on the window luminance and other surface reflections in the test office which determine how much light from the window is then reflected off the screen. It may be the low visual comfort levels experienced by users during this experiment were a factor of a number of things: the low adaptation luminance (relatively higher wall luminance), the reflected luminance off the laptop screen *and* the greatly reduced luminance contrasts within the laptop screen. If we look at the relative subjective appraisals for the different screen contrasts, the adaptation luminance and screen luminance present under each window luminance, this data supports the theory that low visual comfort levels can still be experienced under conditions typically associated with disability glare (even more so than conditions where one would *expect* low visual comfort).

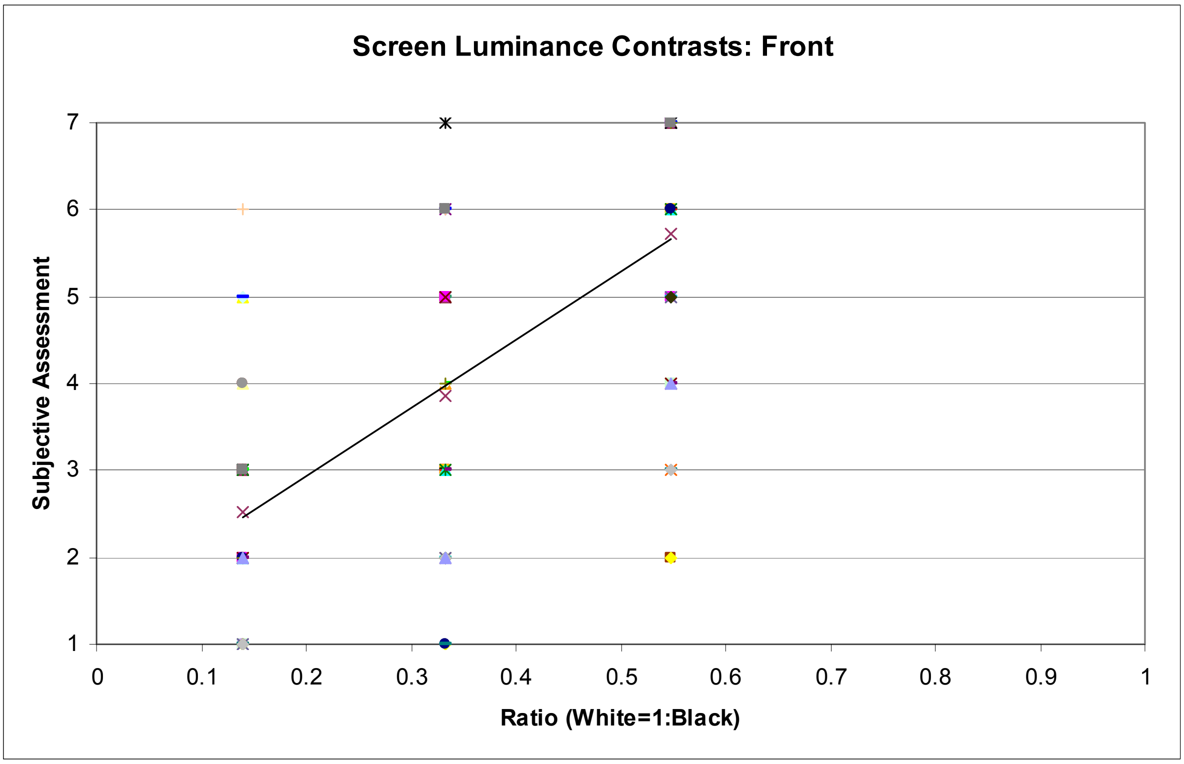


Figure 5.02 Screen contrast distribution tests 1 – 3 (window front variation) versus average and distribution of subjective comfort responses

Figure 5.03 Screen contrast distribution tests 4 – 6 (window left variation) versus average and distribution of subjective comfort responses

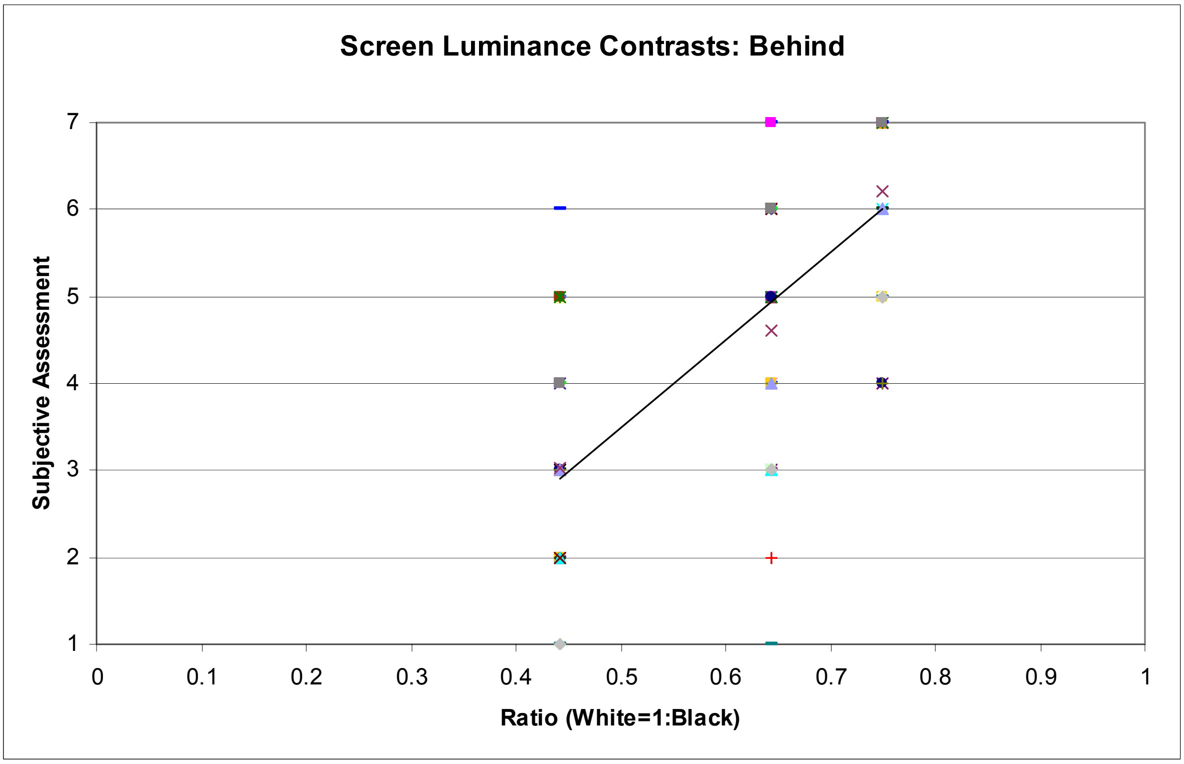


Figure 5.04 Screen contrast distribution tests 7 – 9 (window behind variation) versus average and distribution of subjective comfort responses

The results in this section of the report, illustrate the relationship between subjective comfort responses and the luminance ratios within the confines of the laptop screen (specifically, the ratio of the black letters luminance to the white background luminance - which as documented previously was pre-set at a luminance setting of 100cd/m2). The position of the data in each window variation shows the relative positions of the laptop screen contrasts present during each of the different window luminances/position permutations. We can quickly see from the graphs that the 'window left' variation had the highest screen contrasts, followed by the 'window front' and 'window behind' variations (respectively). This intuitively makes sense as the 'window behind' variation was designed specifically to cause veiling reflections which have the primary effect of reducing screen contrast. While the 'window left' variation could potentially have lower screen contrasts than the 'window front' variation as more direct light is able to reach the screen, this was not observed during the test. This is likely caused by the laptop screen being closer to the white walls surrounding the experiment office than in the 'window left variation' (see schematics in section 2.3). As all the walls are matte white, with a recorded reflectance of approximately 0.8 a reasonable amount of the direct light from the window reaching the wall behind the user in the 'window front' variation will be reflected back towards the screen causing those lower contrast levels than the 'window left' variation.

When we deal with contrast ratios on the laptop screen, it is the opposite direction which adversely affects productivity or comfort. A higher ratio indicates that the black is easier to distinguish from the white and this in turn makes the letters easier to count and the gaps in the black rings easier to find quickly (which could be attributed to why errors and duration increased as the window luminance increased suggesting that it was not solely the ratios between the task area and the window or adaptation levels which disturbed subjects). The typical maximum recommended ratio within the task area is 3:1 but this likely does not apply to within VDU area contrasts. This inverse logic is aptly illustrated below. The 'window behind variation' had all of the screen contrast ratios within recommended limits but this is at odds with the comfort and productivity results. In the same way, all of the 'window left variation' contrasts are outside of recommended limits but this position resulted in the best overall comfort and productivity and highest BCD.

In the 'Window front' variation, the luminance contrasts were as follows:

0.139 or 7.2 times dimmer than the numeric brightness of the white parts of the screen
0.333 or 3 times dimmer than the numeric brightness of the white parts of the screen
0.548 or 1.84 times dimmer than the numeric brightness of the white parts of the screen

Table 5.01 On-screen luminance ratios – Window front

In the 'window left' variation, the luminance contrasts were as follows:

0.067 or 15 times dimmer than the numeric brightness of the white parts of the screen
0.156 or 6.4 times dimmer than the numeric brightness of the white parts of the screen
0.28 or 3.57 times dimmer than the numeric brightness of the white parts of the screen

Table 5.02 On-screen luminance ratios – Window left

In the 'window behind' variation, the luminance contrasts were as follows:

0.44 or 2.27 times dimmer than the numeric brightness of the white parts of the screen
0.64 or 1.56 times dimmer than the numeric brightness of the white parts of the screen
0.75 or 1.33 times dimmer than the numeric brightness of the white parts of the screen

Table 5.03 On-screen luminance ratios – Window behind

5.1 Subjective Assessment and Errors

The lines between the factors which result in discomfort or disability glare appear somewhat blurred. Both visual comfort and most facets of productivity decline as the window luminance increases even in layouts specifically designed to cause only one or the other. This is particularly clear in the window behind variation which displayed lower productivity levels (with the exception of the letter count duration discussed previously) as we would expect due to the high degree of veiling reflections but also displayed the lowest overall visual comfort levels. Because it is difficult to deduce the exact causal factors (or at least the weightings of the different causal factors) of disability or discomfort it is important to analyse the decline in the objective factors in comparison to the subjective factors. If a link between the two lighting quality assessment types did exist, then understanding the implications of a given decline in visual comfort on likely productivity (and vice versa) could aid lighting designers, architects or interior designers by yielding a greater understanding of the likely impact of any particular lighting design even if data on only comfort or productivity were available.

5.1.1 Window in Front of User Field of View

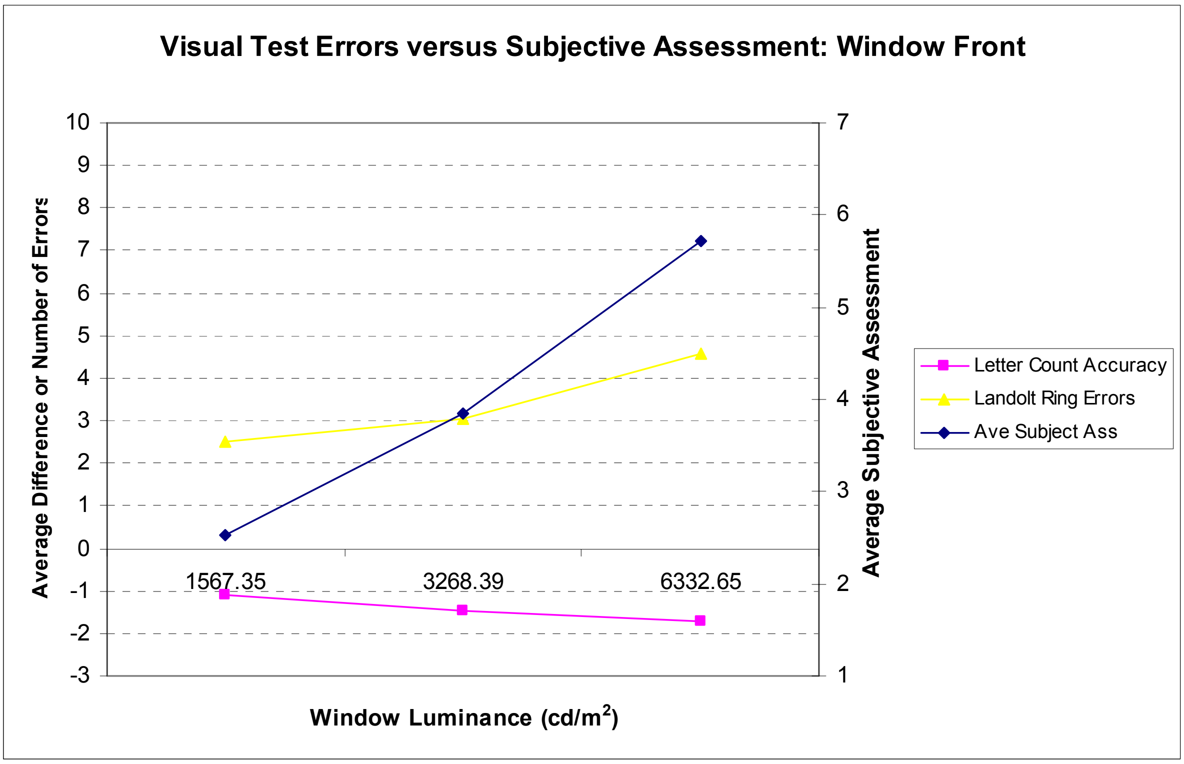


Figure 5.05 Visual test errors VS Overall subjective assessment – Tests 1 – 3 (window front variation)

	Test 1 → 2	Test 1 → 3
Letter Count Inaccuracy % Increase	+ 32.7%	+ 55.5%
Landolt Ring Errors % Increase	+ 21.4%	+ 81.7%
Visual Comfort % Decline	+ 52.8%	+ 127.4%

Table 5.04 Relative percentage increases/decreases in visual test errors and visual comfort – Window front variation

At first glance the results in this position make intuitive sense. In this non-OSH (see figures 2.09 and 2.10) recommended layout with the glare source directly in front of the user visual comfort declined at distinctly higher rates than productivity did. This position was designed for discomfort glare as the high luminance in the field of view would not create veiling reflections (all light hitting the screen was reflected off the walls) meaning screen contrast would still be relatively high. However it cannot be said that the position causes discomfort alone as productivity was also noticeably impacted upon (albeit to a smaller degree) so in this way the results can conclude that glare affects both comfort and productivity regardless of whether the luminous conditions would normally only be associated with one type of glare (possible causal factors for why each was affected are discussed on page 93).

5.1.2 Window 90° Left of User Field of View

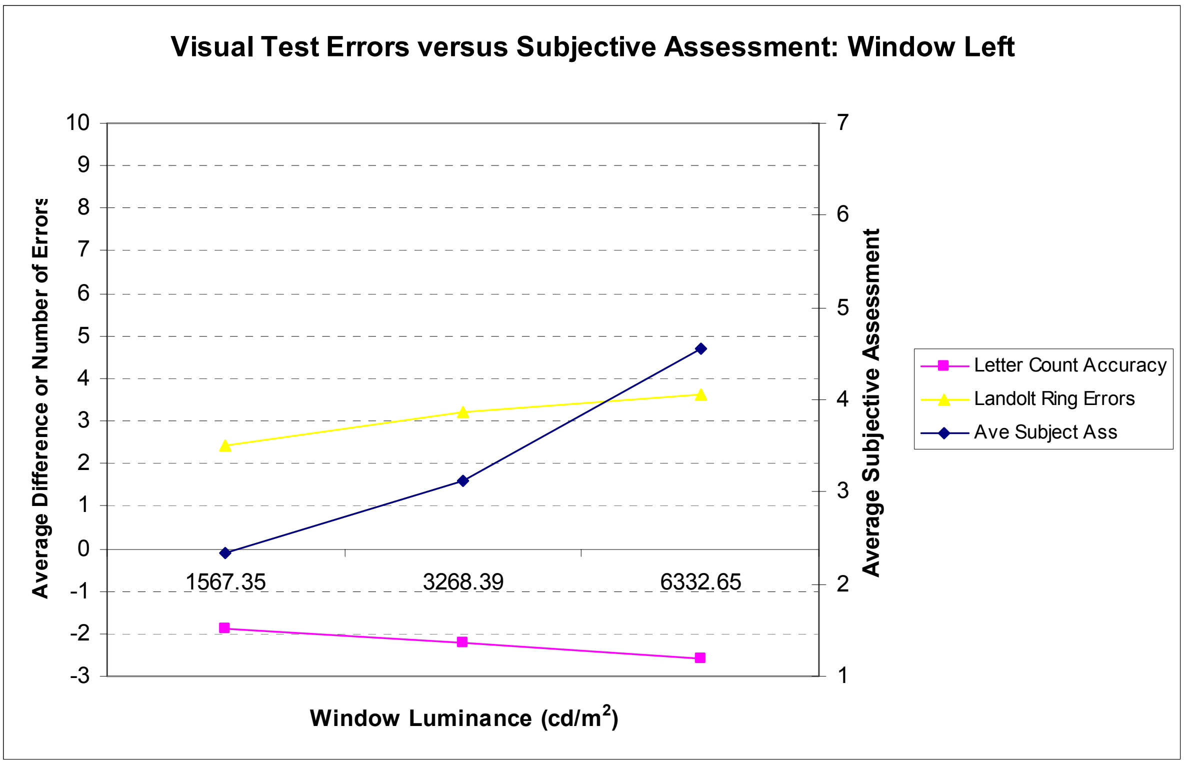


Figure 5.06 Visual test errors VS Overall subjective assessment – Tests 4 – 6 (window left variation)

	Test 4 → 5	Test 4 → 6
Letter Count Inaccuracy % Increase	+ 17.4%	+ 35.8%
Landolt Ring Errors % Increase	+ 31.6%	+ 50.0%
Visual Comfort % Decline	+ 33.9%	+ 95.7%

Table 5.05 Relative percentage increases/decreases in visual test errors and visual comfort – Window left variation

In the case of the recommended office layout, visual comfort in the first instance between the lower and middle order window luminance declined at a comparable rate to productivity. Since visual comfort has largely been shown to decline noticeably faster than productivity, it could be said that using the recommended layout mitigates the negative effects of luminances up till a certain luminance threshold. However after this threshold the rate of decline in visual comfort is once again much higher than the rate of decline in productivity, although the rate of decline in productivity after the same threshold actually decreases. This suggests that if visual discomfort effects (pain, dizziness etc) have a link with productivity, then the impact visual discomfort has on productivity declines as window luminance increases (at least for this recommended layout).

5.1.3 Window 180° Behind User Field of View

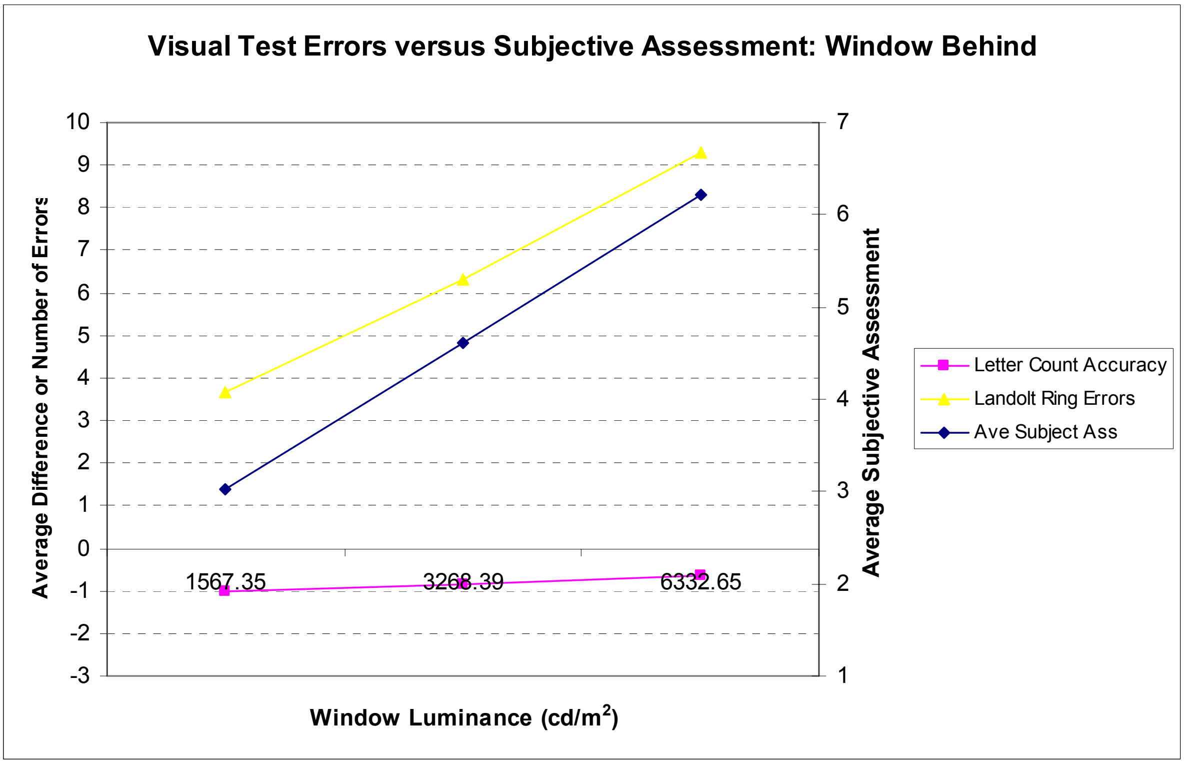


Figure 5.07 Visual test errors VS Overall subjective assessment – Tests 7 – 9 (window behind variation)

	Test 7 → 8	Test 7 → 9
Letter Count Inaccuracy % Increase	- 16.7%	- 36.7%
Landolt Ring Errors % Increase	+ 72.5%	+ 154.0%
Visual Comfort % Decline	+ 53.3%	+ 107.0%

Table 5.06 Relative percentage increases/decreases in visual test errors and visual comfort – Window behind variation

Even if the overall level of visual discomfort or decline in productivity have appeared out of line with typical definitions of glare and their factors/effects, the actual rates of decline in each scenario have made intuitive sense. Regardless of the actual values, in scenarios designed to cause discomfort glare the rate of increase of visual discomfort was greater than that of productivity and the inverse was true for scenarios designed to cause disability (although this knowledge may have no real value since it is the actual level of discomfort not the rate of increase unless that window luminance was exceptionally high that will cause problems).

5.2 Subjective Assessment and Duration

Normally when one considers the likely implications of poor visual comfort, it appears intuitively obvious that if someone is uncomfortable then test performance would decrease. In terms of visual test duration this has previously meant an increase in the time taken to perform the test. However, we must now not entirely abandon this line of thought but for the moment consider the possibility exists also that test subjects who are experiencing visual discomfort would feel somewhat of an urgency to end the test and so too their feeling of discomfort by rushing through the test (although this would more than likely be reflected in the accuracy of their answers whereby the number of errors could be affected – section 4.0 errors results). This reinforces the notion of exploring the visual test duration alongside the test subjects subjective responses of visual comfort levels.

5.2.1 Window in Front of User Field of View

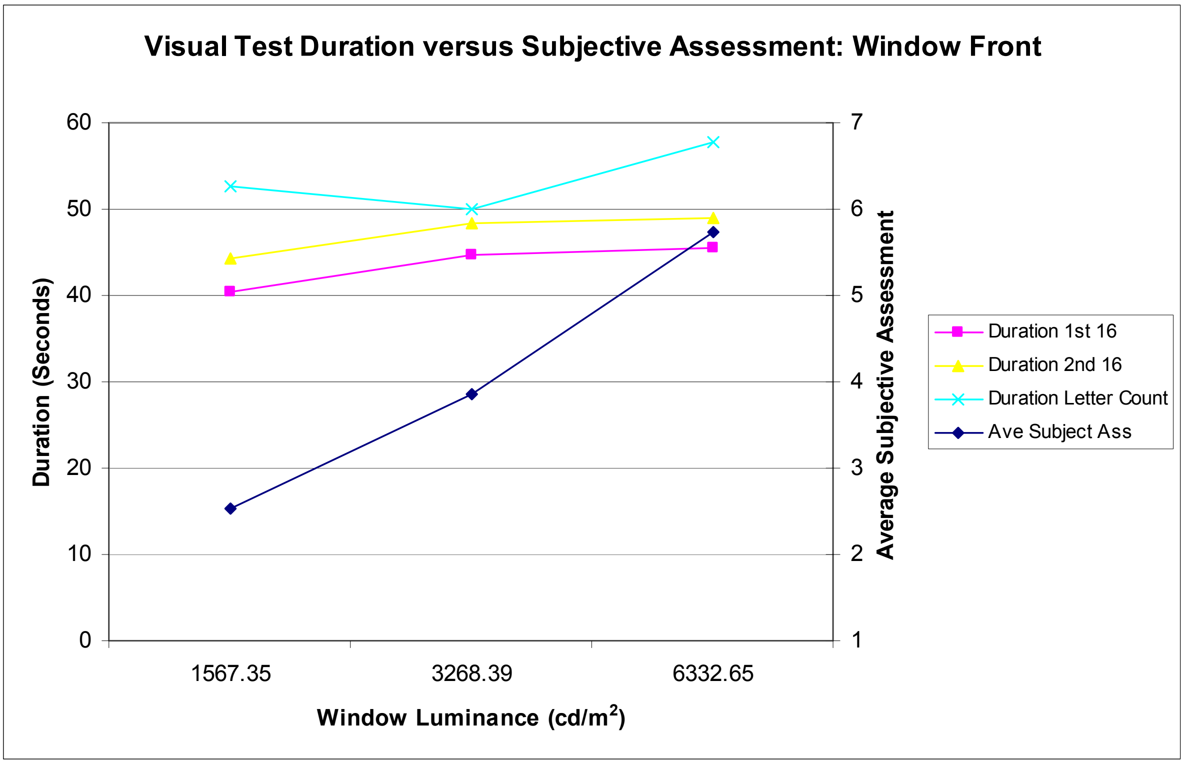


Figure 5.08 Visual test durations VS Overall subjective assessment – Tests 1 – 3 (window front variation)

	Test 1 → 2	**Test 1 → 3**
Letter Count Duration % Increase	- 5.1%	+ 9.8%
1st 16 Landolt Rings' Duration % Increase	+ 10.6%	+12.4%
2nd 16 Landolt Rings' Duration % Increase	+ 9.5%	+ 10.5%
Visual Comfort % Decline	+ 52.8%	+ 127.4%

Table 5.07 Relative percentage increases/decreases in visual test duration and visual comfort – Window front variation

The results from the window front variation suggest that visual comfort does not have a strong impact on the duration of the visual tests. Overall visual comfort levels declined at much higher rates than test durations declined at in the first instance. Visual comfort also declined much faster after the middle order window luminance but this did not result in a comparable decline rate for test duration. Visual comfort and duration may either be mutually exclusive or after a certain discomfort threshold, a large decline in visual comfort will not cause a large impact on durational productivity.

5.2.2 Window 90° Left of User Field of View

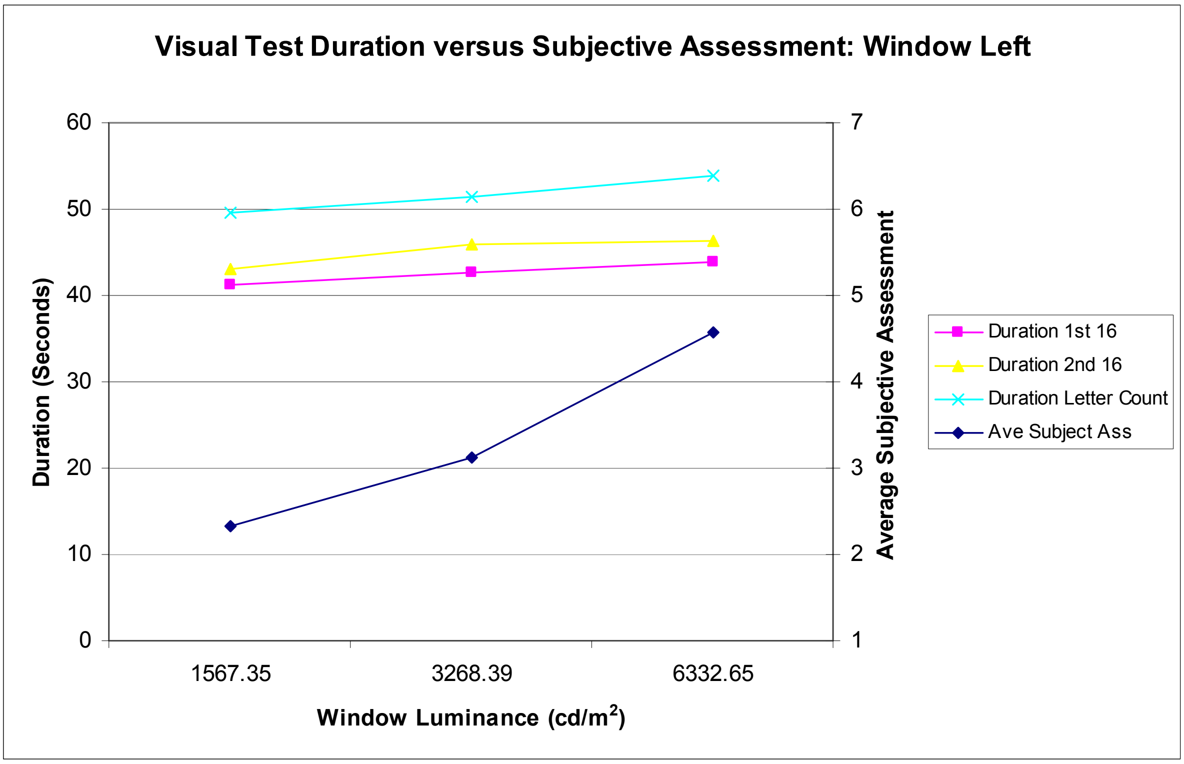


Figure 5.09 Visual test durations VS Overall subjective assessment – Tests 4 – 6 (window left variation

	Test 4 → 5	Test 4 → 6
Letter Count Duration % Increase	+ 3.5%	+ 8.6%
1st 16 Landolt Rings' Duration % Increase	+ 3.4%	+ 6.4%
2nd 16 Landolt Rings' Duration % Increase	+ 6.6%	+ 7.5%
Visual Comfort % Decline	+ 33.9%	+ 95.7%

Table 5.08 Relative percentage increases/decreases in visual test duration and visual comfort – Window left variation

The window left variation displayed a similar trend between visual comfort and test durations. Test durations displayed small increases while discomfort rates got incrementally much larger as window luminance was increased. The results here support the conclusion reached previously that while visual comfort may impact upon some facets of productivity including duration, a relatively large decrease in overall visual comfort results in or is usually observed with a comparatively small decrease in efficiency.

5.2.3 Window 180° Behind the Field of View

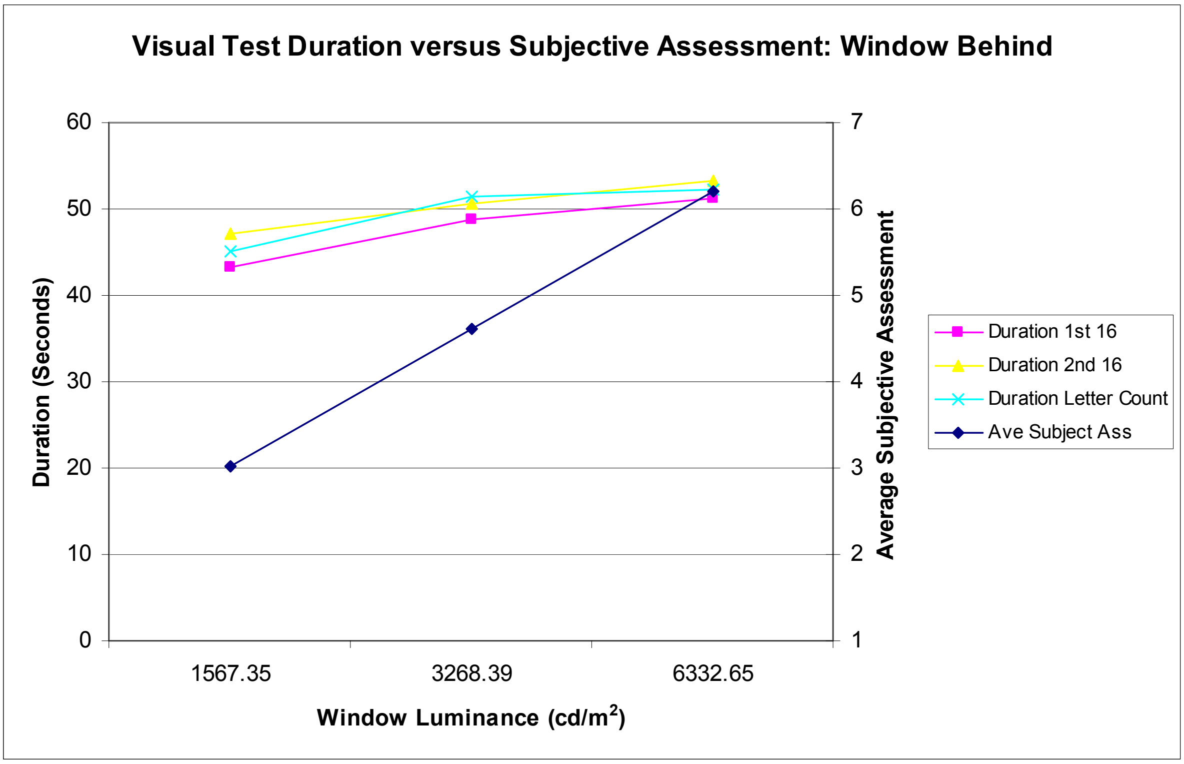


Figure 5.10 Visual test durations VS Overall subjective assessment – Tests 7 – 9 (window behind variation

	Test 7 → 8	Test 7 → 9
Letter Count Duration % Increase	+14.1 %	+ 15.9%
1st 16 Landolt Rings' Duration % Increase	+ 12.7%	+ 18.2%
2nd 16 Landolt Rings' Duration % Increase	+ 7.3%	+ 12.9%
Visual Comfort % Decline	+ 53.3%	+ 107.0%

Table 5.09 Relative percentage increases/decreases in visual test duration and visual comfort – Window behind variation

Again, visual comfort decline rates were much higher than the decline rates in durational efficiency. All of the results from the experiment suggest that if visual comfort is tied to productivity (see section 5.0 on page 93 for discussion regarding the possible causal factors of such a link) then large reductions in visual comfort, result in small losses in productivity or inversely, if a user finds a task only slightly more difficult to perform due to lighting conditions thereby increasing duration or errors, a large decline in visual comfort could be expected. Further research into this specific possibility could help confirm this.

6.0 Results among Specific Groups of Users

In this section, the results for subjective assessments of the nine different luminance distributions and layouts are analysed in relation to particular survey questions. This section details user characteristics where potential trends/correlations were found (although full user characteristics analysis from the survey can be found in appendix four). Hypotheses/predictions have been put forward with possible explanations of why the experiment results did or did not agree with them.

6.1 Illumination Preference

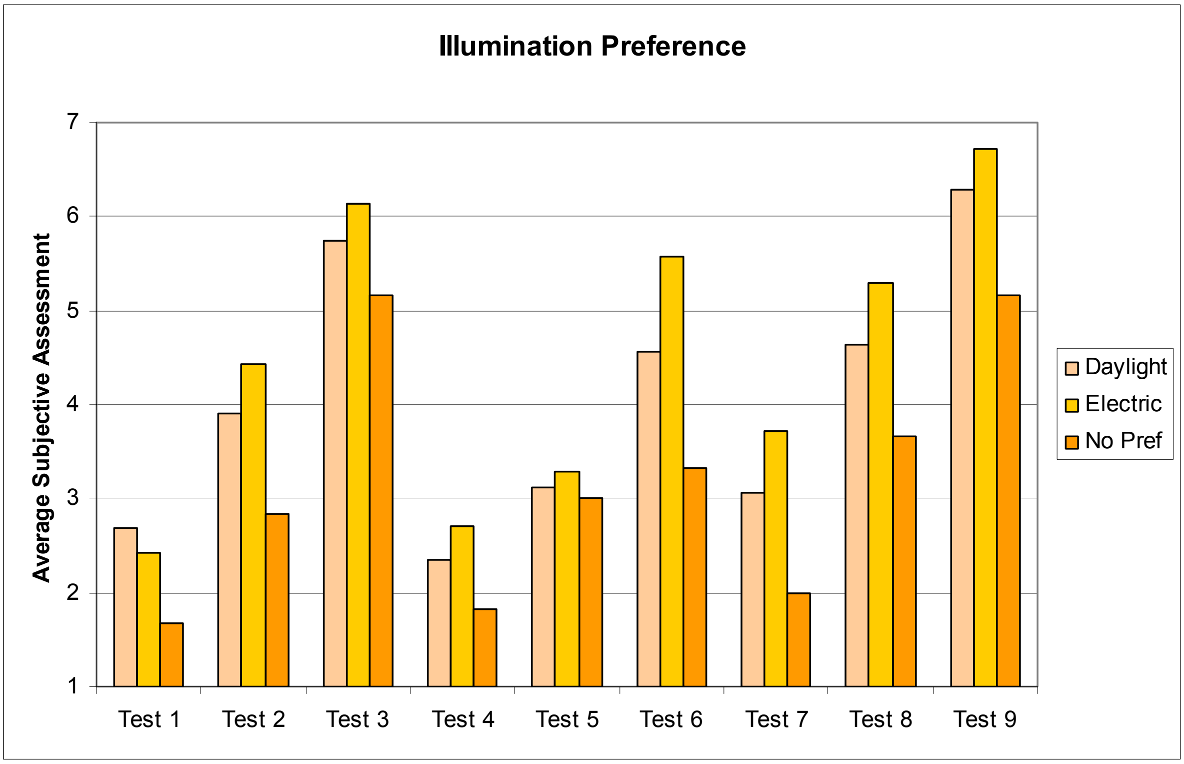


Figure 6.01 Distribution of subjective comfort appraisal responses with respect to illumination preference

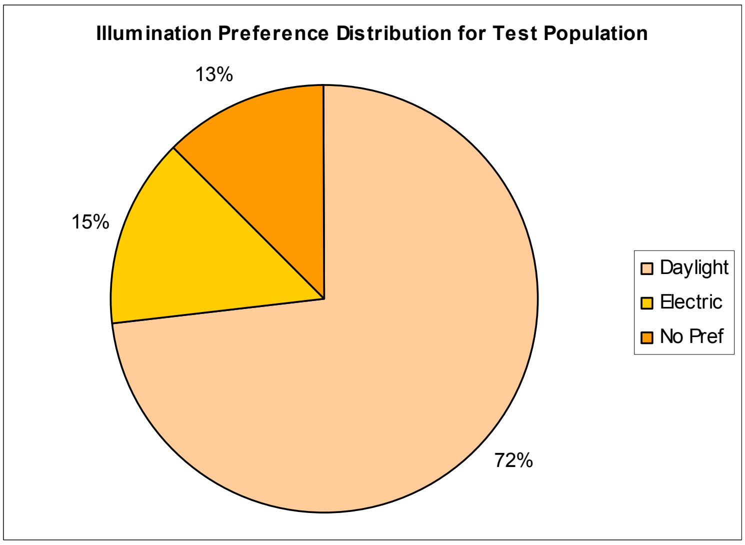


Figure 6.02 Distribution of illumination preference from user survey

The test population's illumination preference was documented to see if this had an impact on the average subjective assessment level. Subjects were given three possible responses for their illumination preference: Daylight (DL), Electric (or artificial) light (EL) or No-Preference (NP). It was expected that subjects who preferred daylight illumination would find the conditions more comfortable than those who preferred illumination by artificial means. No particular trend was predicted for those who had no preference other than a decline in comfort as the window luminance increased which would follow the average for the entire population. The results from the survey agree with the hypothesis, although most clearly at the middle and highest ratios/luminances. The subjects who had no preference showed higher visual comfort responses across all of the tests. Since a small number of subjects gave this response in comparison to those who responded 'daylight' nothing conclusive can be said about this group of users although the results do suggest further study into illumination preference and daylight glare perception could be warranted. The trend of daylight preference users being more comfortable during any test did not always come through at the lowest settings. However, since most of the population was below the BCD at this window luminance, it is possible that the impact of the glare source on these different user groups simply had not come into effect yet.

Test no. Window Pos	Average	% Variance DL	% Variance EL	Overall % Difference
Test 1 (front)	2.52	+ 6.54	- 3.66	- 3.67
Test 2 (front)	3.85	+ 1.56	+ 14.90	+ 7.35
Test 3 (front)	5.73	+ 0.24	+ 7.22	+ 5.71
Test 4 (left)	2.33	+ 0.41	+ 16.33	+ 5.31
Test 5 (left)	3.13	- 0.34	+ 5.14	+ 2.45
Test 6 (left)	4.56	+ 0.20	+ 22.11	+ 14.29
Test 7 (behind)	3.02	+ 1.20	+ 22.96	+ 9.39
Test 8 (behind)	4.60	+ 0.53	+ 14.80	+ 9.39
Test 9 (behind)	6.21	+ 1.25	+ 8.15	+ 6.12

Table 6.01 Comparison of overall test population subjective assessments and specific user-groups (illumination preference)

6.2 Users with Office Windows versus Users without

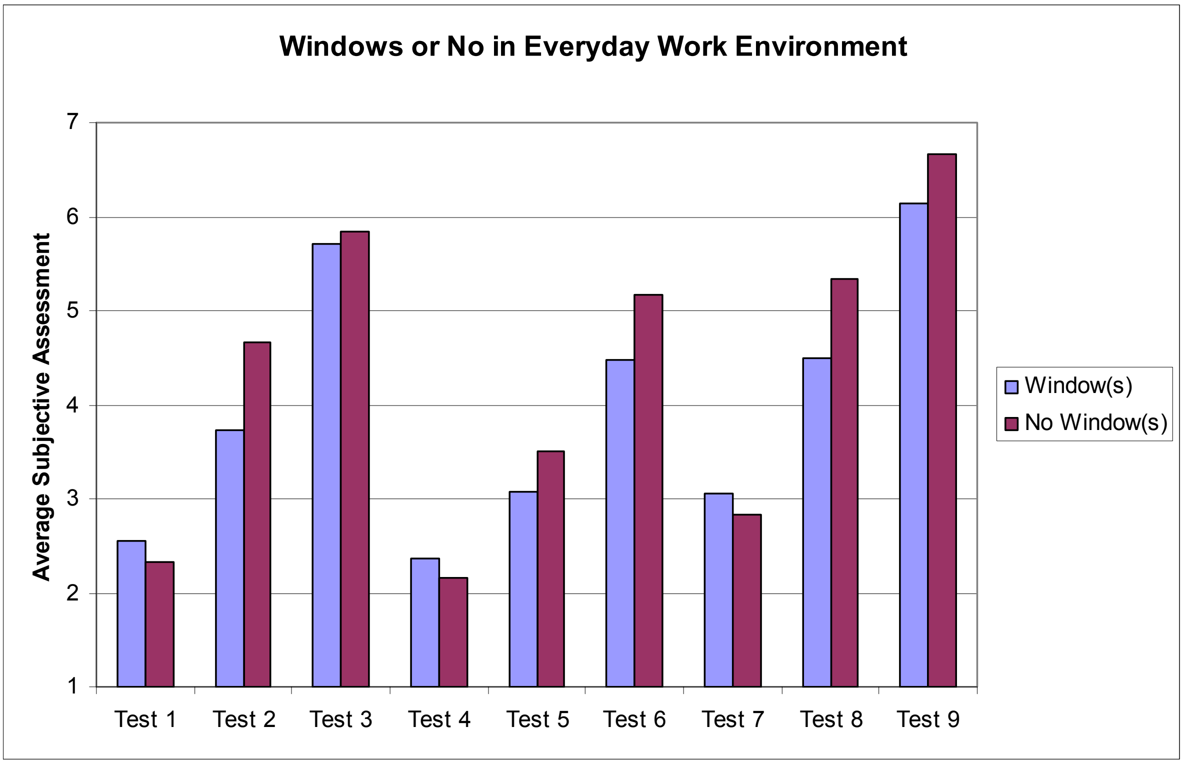


Figure 6.03 Distribution of subjective comfort appraisal responses with respect to whether or not the user has windows in their everyday place of work

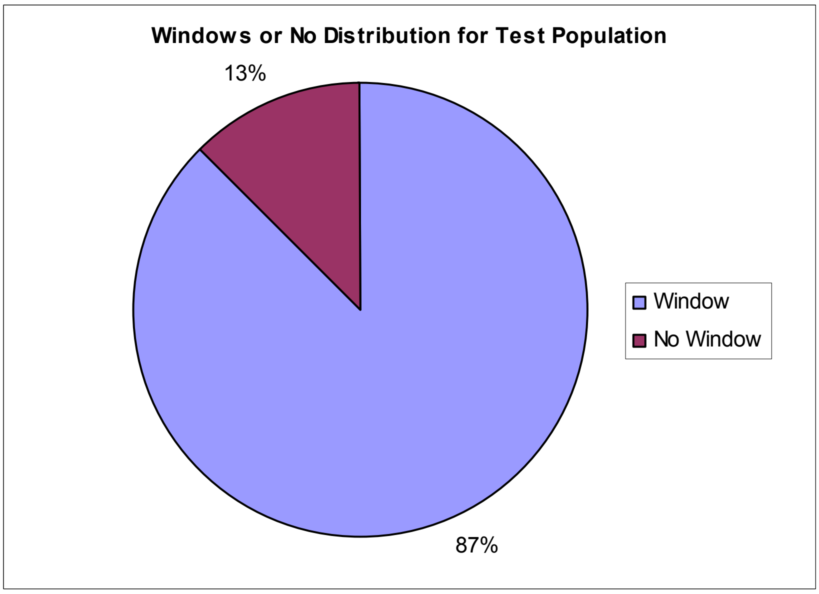


Figure 6.04 Distribution of users with/without windows in their everyday place of work from user survey

Whether or not users had a window in their office at all was documented. Irrespective of the size of the window it was hypothesized that users who were exposed to daylit environments during their everyday working life would experience visual discomfort to a less severe degree than those who worked in artificially lit environments. The results from the experiment support this hypothesis with subjects from artificially lit environments being on average 5.6% higher in their assessment of visual discomfort. However, only 12.5% of the population did not have windows so the hypothesis cannot be conclusively proved one way or the other. This trend could warrant further investigation into the impact of window vs. windowless work spaces and their impact on subjective glare assessments amongst those space users (also the impact of window size and orientation which was recorded in the user survey may have some effect worth investigating but further analysis of the data is required before such correlations can be tested).

Test no. Window Pos	Average	% difference Window - Ave	% difference No Window - Ave	Overall % Difference - Between
Test 1 (front)	2.52	+ 1.06	- 7.44	- 3.06
Test 2 (front)	3.85	- 3.01	+ 21.08	+ 13.27
Test 3 (front)	5.73	- 0.26	+ 1.82	+ 1.70
Test 4 (left)	2.33	+ 1.02	- 7.14	- 2.72
Test 5 (left)	3.13	- 1.71	+ 12.00	+ 6.12
Test 6 (left)	4.56	- 1.89	+ 13.24	+ 9.86
Test 7 (behind)	3.02	+ 0.89	- 6.21	- 3.06
Test 8 (behind)	4.60	- 2.26	+ 15.84	+ 11.90
Test 9 (behind)	6.21	- 1.05	+ 7.38	+ 7.48

Table 6.02 Comparison of overall test population subjective assessments and specific user-groups (windows VS no windows in everyday place of work)

6.3 Average Daily VDU Usage

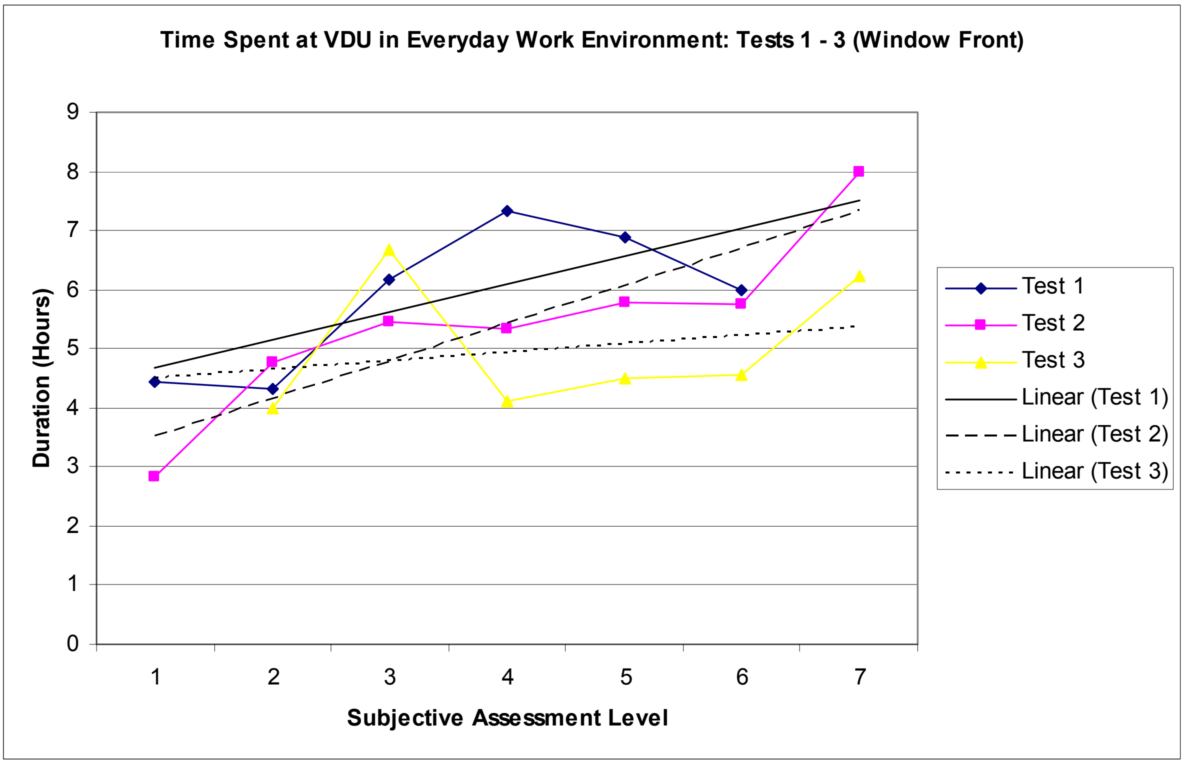


Figure 6.05 Overall subjective appraisal versus number of hours typically spent in front of VDU during normal working day – Tests 1 – 3 (window front variation)

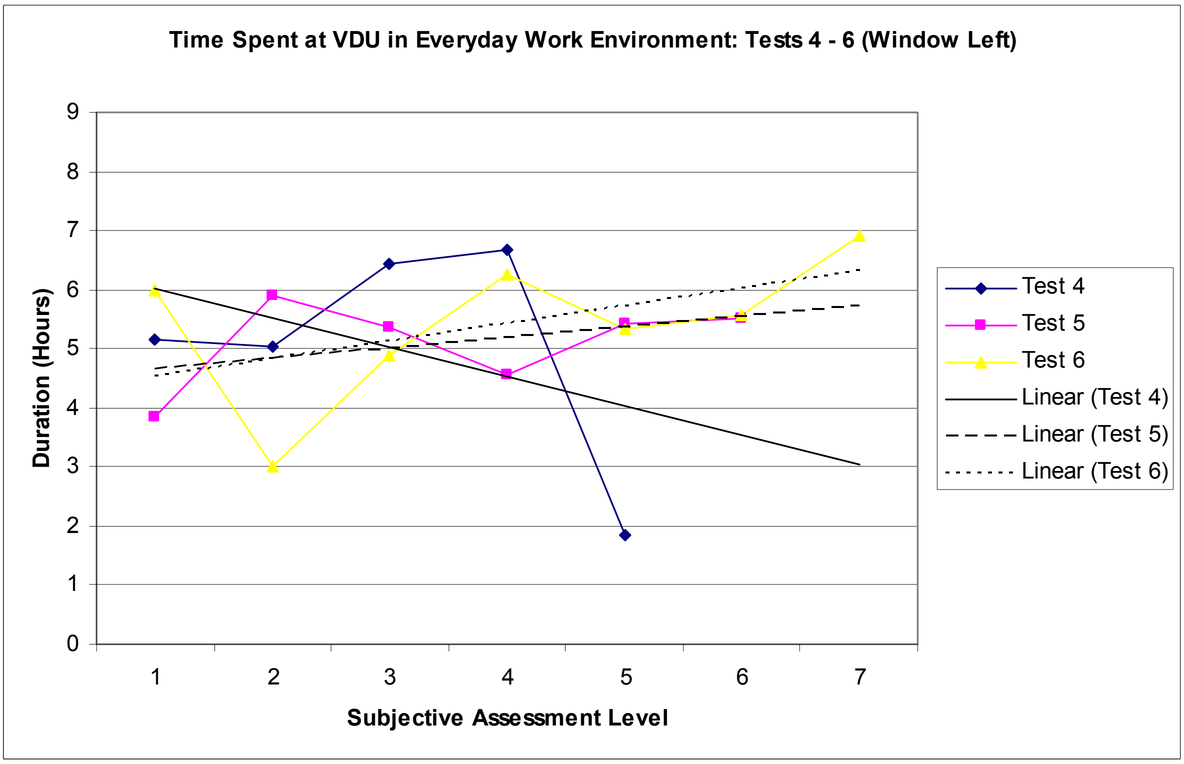


Figure 6.06 Overall subjective appraisal versus number of hours typically spent in front of VDU during normal working day – Tests 4 – 6 (window left variation)

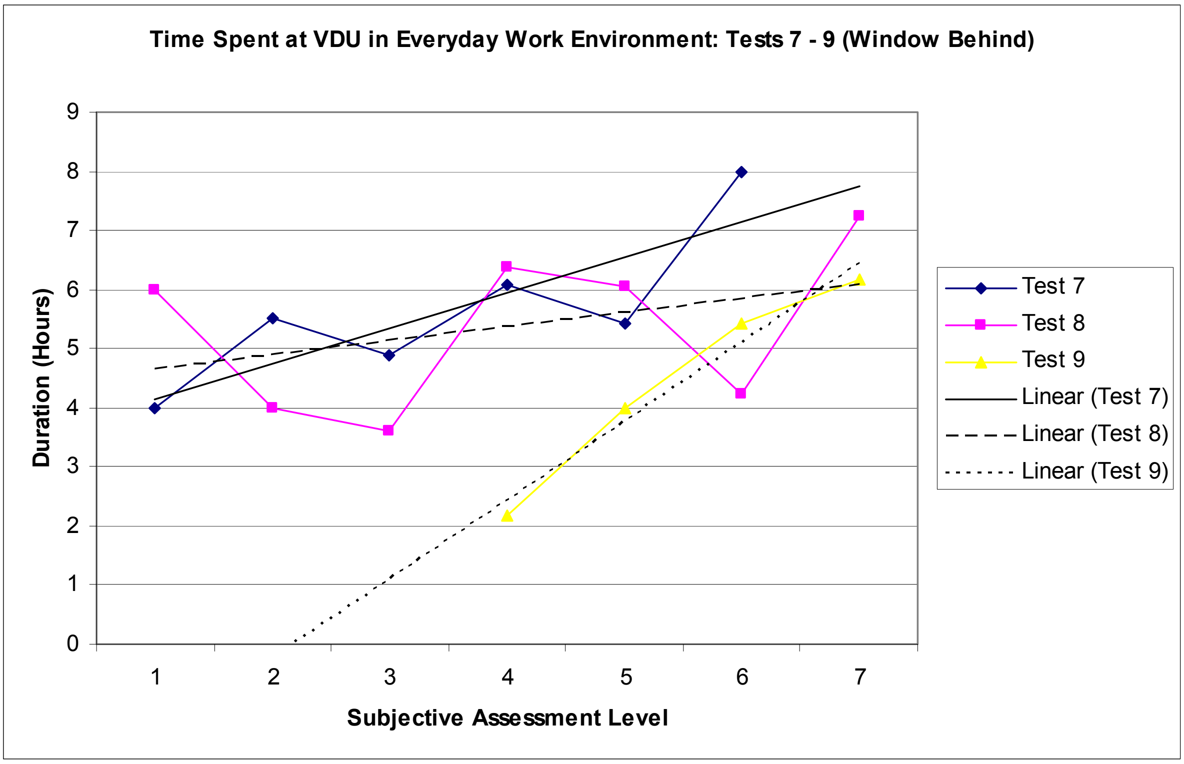


Figure 6.07 Overall subjective appraisal versus number of hours typically spent in front of VDU during normal working day – Tests 7 – 9 (window behind variation)

Perhaps one of the clearest correlations and especially in tests 1 -3 and 7 - 9 where the window was in the non-recommended positions of either completely within the field of view or shining on the task area from behind was the average responses of test subjects as the average number of hours they spent at a VDU during a normal working day increased. The hypothesis was that users who spent more time at a VDU would have a clearer idea of the conditions which were conducive to their comfort and productivity and would therefore be more critical of lighting conditions which they felt were suboptimal in comparison to what they would normally consider as 'good lighting' conditions.

From tests 1 -3 and 7 - 9, the number of hours and percentage increases in VDU duration in users' normal offices between visual comfort being satisfactory and intolerable (appraisal '1' → '7') irrespective of whether or not users gave those responses, and between assessment interval percentage increases are outlined below:

Test no. Window Pos	Satisfactory → Intolerable (Hours)	Satisfactory → Intolerable (%)	Between intervals (%)
1 (front)	+ 0.9 Hrs	+ 19.5%	+ 3.25%
2 (front)	+ 3.8 Hrs	+ 108.5%	+ 18.09%
3 (front)	+ 2.8 Hrs	+ 60.4%	+ 10.07%

Table 6.03 Increase in VDU duration for everyday workplace from subjective appraisals' 1 – 7 – Window front variation

Test no. Window Pos	Satisfactory → Intolerable (Hours)	Satisfactory → Intolerable (%)	Between intervals (%)
7 (behind)	+ 3.6 Hrs	+ 86.6%	+ 14.43%
8 (behind)	+ 1.4 Hrs	+ 30.5%	+ 5.09%
9 (behind)	+ 8.0 Hrs	+ 504.9%	+ 84.1%

Table 6.04 Increase in VDU duration for everyday workplace from subjective appraisals' 1 – 7 – Window behind variation

Across both of these scenarios, there were noticeable increases in VDU duration during a normal working day and visual discomfort although these are not necessarily in order of ascending window luminance.

This trend was not as strong when the window was perpendicular to the workstation (tests 4 - 6), although the two highest ratios still show a clear overall increase in VDU duration. Despite the lowest ratio displaying a downwards trend in VDU duration with increasing subjective assessment level, this can be explained by the majority of the population showing satisfactory visual comfort levels and therefore the impact of the glare source on any one user group being negligible at this luminance. The average percentage increases in VDU duration as visual discomfort increased for this position are as follows:

Test no. Window Pos	Satisfactory → Intolerable (Hours)	Satisfactory → Intolerable (%)	Between intervals (%)
4 (left)	- 3.0 Hrs	- 49.7%	- 8.28%
5 (left)	+ 1.1 Hrs	+ 22.6%	+ 3.76%
6 (left)	+ 1.8 Hrs	+ 39.3%	+ 6.56%

Table 6.05 Increase in VDU duration for everyday workplace from subjective appraisals' 1 – 7 – Window left variation

If there is a link between VDU duration during a normal working day and subjective assessment of lighting conditions then once again, the perpendicular workstation has shown to be beneficial. The effects of the glare source are mitigated sufficiently at low window luminances such that VDU duration is no longer affecting subjective appraisal. In any case, the majority of these results suggest that when doing lighting design for an office, the length of time the space users are likely to be using a VDU could be an important factor in the determining the likely overall visual comfort levels.

For example, if two spaces were being designed and both were to have VDUs used in them, but the first space was likely to have users in front of those VDUs for a longer portion of the working day then this space would require more careful attention to glare likelihood than the latter space.

6.4 Users with Corrective Lenses versus Users without

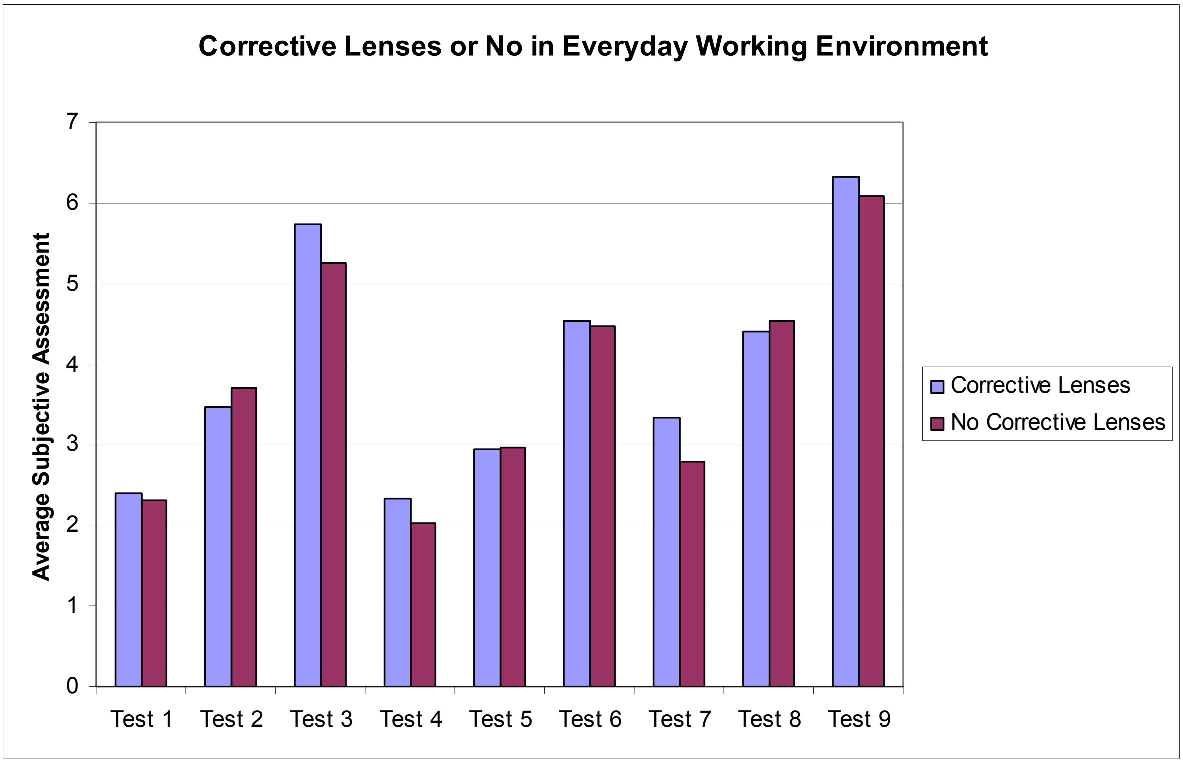


Figure 6.08 Distribution of subjective comfort appraisal responses with respect to whether or not the user normally wears corrective lenses when working at a computer

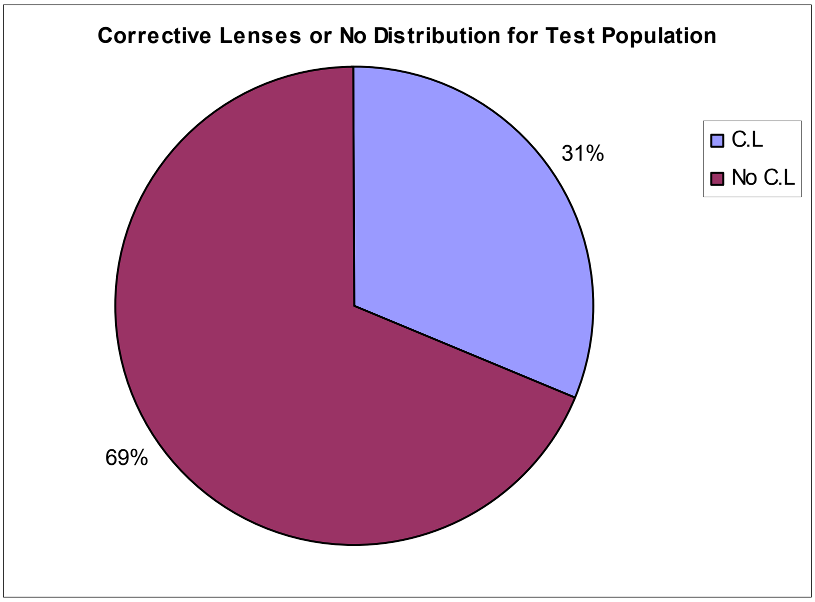


Figure 6.09 Distribution of users who do/do not normally wear corrective lenses when working at a computer

It was hypothesized that subjects who normally wear corrective lenses at a computer screen would experience more severe visual discomfort than those whom do not normally wear corrective lenses. Corrective lenses can be either glasses or contact lenses (this information was also recorded in the survey). 6 of the 9 tests support this hypothesis (irrespective of window position or luminance). All of the tests with the highest window luminance showed those subjects who normally wear some type of corrective lenses were on average experiencing higher visual discomfort (albeit a small increase in some cases). However the trend was not present in the middle window luminance tests and this is difficult to explain except for the possibility that no real correlation exists. However as two thirds of the overall test responses support the hypothesis this could warrant further investigation into eye condition effects on subjective glare perception. Possible reasons for the users who normally wear glasses being more affected by visual discomfort include:

1 - Inter-reflections - When the window is either perpendicular or behind the user, some amount of direct light actually reaches behind the user's glasses and is then reflected into the eye. This may cause sufficient luminance spots on the glass lenses to cause the user visual discomfort. However it is difficult to prove this from this experiment as some users with corrective lenses wear contact lenses where this effect would not be in play and also because not all users who normally wear corrective lenses at a VDU wore them during the experiment.

2 - Eye condition - The fact that the user needs corrective lenses in order to see properly suggests that some visual discomfort may simply arise from the fact that the eye condition is diminished (this could be for a number of reasons including astigmatisms, myopia etc). This diminished eye condition may make certain users more susceptible to the effects of excessively high luminances or luminance ratios within their field of view. Again, this experiment makes no conclusive remarks regarding these user groups and simply identifies possible trends which support the hypotheses made prior to the experimentation.

Test no. Window Pos	Average	% Variance Glasses	% Variance No Glasses	Overall % Difference - Between
Test 1 (front)	2.52	- 4.79	- 8.10	- 1.19
Test 2 (front)	3.85	- 10.05	- 3.57	+ 3.57
Test 3 (front)	5.73	+ 0.07	- 8.36	- 6.90
Test 4 (left)	2.33	0.00	- 12.86	- 4.29
Test 5 (left)	3.13	- 6.13	- 5.07	+ 0.48
Test 6 (left)	4.56	- 0.64	- 2.10	- 0.95
Test 7 (behind)	3.02	+ 10.34	- 7.86	- 7.86
Test 8 (behind)	4.60	- 4.43	- 1.54	+ 1.90
Test 9 (behind)	6.21	+ 2.01	- 2.01	- 3.57

Table 6.06 Comparison of overall test population subjective assessments and specific user-groups (Corrective lenses VS no corrective lenses)

6.5 Workplace Environment Appraisal

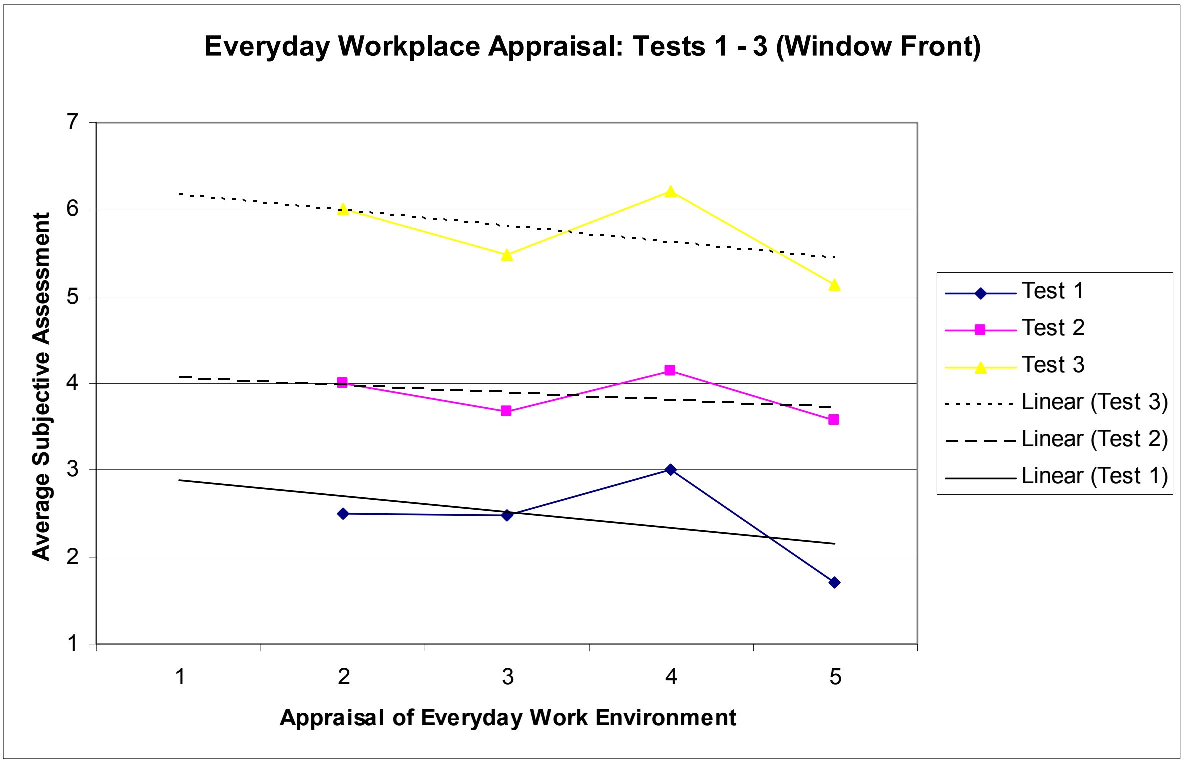


Figure 6.10 Overall users' self-assessment of how they feel in their everyday workplace VS Overall subjective appraisal of comfort – Tests 1 – 3 (window front variation)

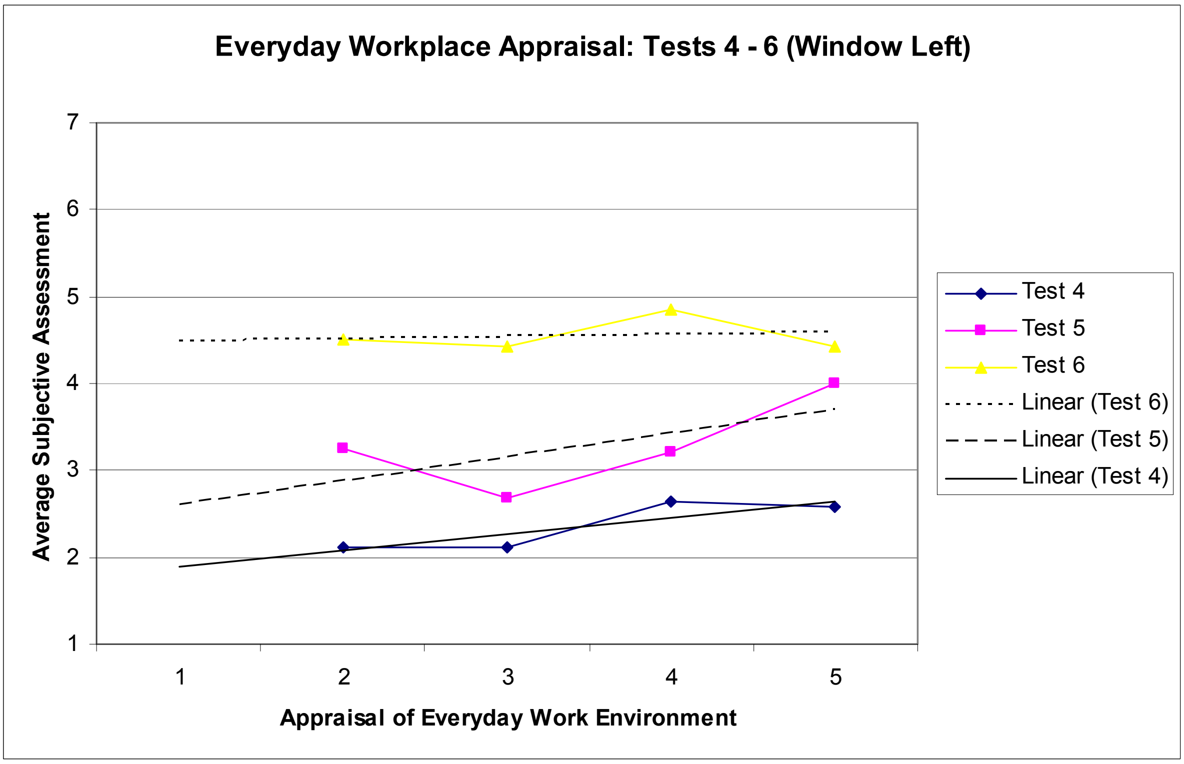


Figure 6.11 Overall users' self-assessment of how they feel in their everyday workplace VS Overall subjective appraisal of comfort – Tests 4 – 6 (window left variation)

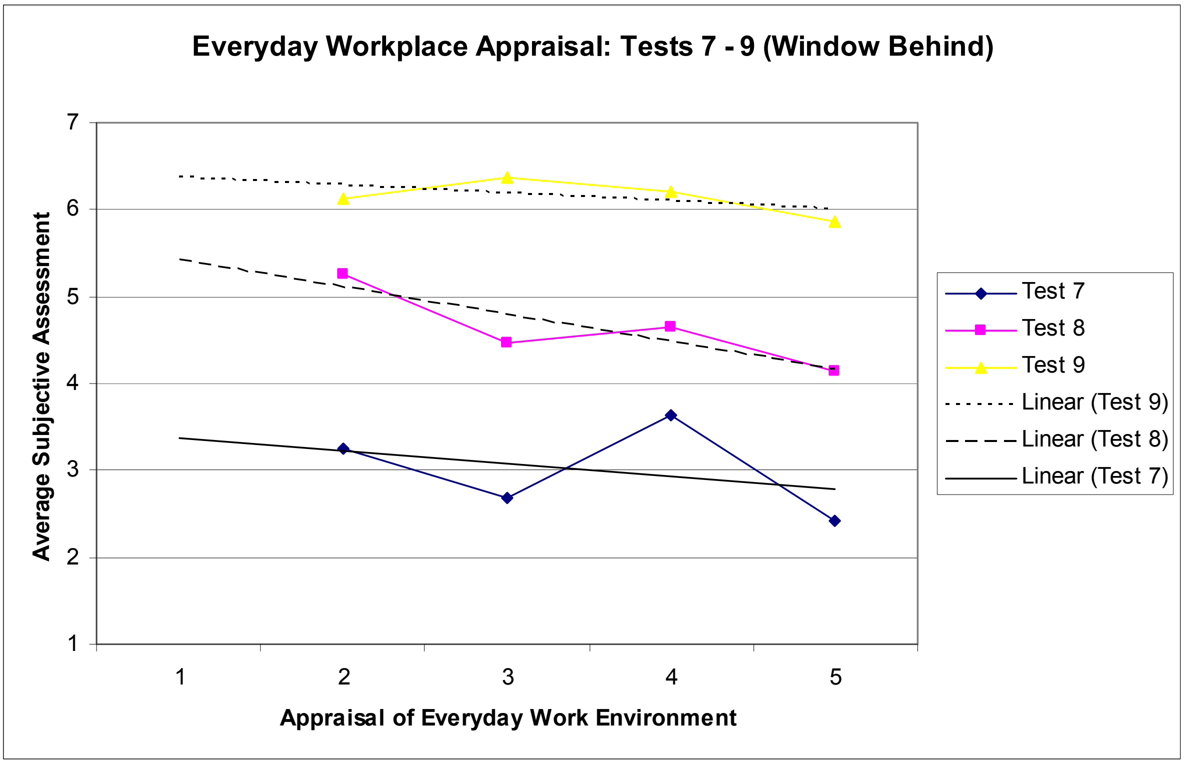


Figure 6.12 Overall users' self-assessment of how they feel in their everyday workplace VS Overall subjective appraisal of comfort – Tests 7 – 9 (window behind variation)

Test subjects were asked in the survey how they felt about their everyday work environment (not specifically about lighting but simply in generic terms). A '1' indicates they felt 'very negative', a '5' indicates they felt 'very positive' with a ''3 being 'average'. It is hypothesized that subjects who feel more negative about their everyday office environment (in generic terms) will be more critical of specific factors such as lighting conditions in the test office. This would be illustrated by a trend over at least the two highest ratios (where the majority of the population were above the BCD) of negative gradients (for the line of best fit) indicating an increase in workplace appraisal with declining visual discomfort.

Nobody from the test population responded as feeling 'very negative' about their everyday work environment although there were those who felt 'very positive'. Still, the front and behind variations agree with the hypothesis. The average percentage decrease per assessment step (1 - 5 from the survey) is shown below:

Test no. Window Pos	'1' → '5' (comfort intervals)	Very Negative '1' → Very Positive '5' (%)	Between intervals '1' → '5' (%)
1 (front)	- 0.73 intervals	- 11.9%	- 2.97%
2 (front)	- 0.33 intervals	- 8.2%	- 2.04%
3 (front)	- 0.73 intervals	- 25.4%	- 6.36%

Table 6.07 Decrease in visual comfort from subjective appraisals' 1 - 5 of everyday workplace wellbeing – Window front variation

Test no. Window Pos	'1' → '5' (comfort intervals)	Very Negative '1' → Very Positive '5' (%)	Between intervals '1' → '5' (%)
4 (left)	+ 0.09 intervals	+ 2.0%	+ 0.49%
5 (left)	+ 1.11 intervals	+ 42.9%	+ 10.72%
6 (left)	+ 0.75 intervals	+ 39.7%	+ 9.92%

Table 6.08 Decrease in visual comfort from subjective appraisals' 1 - 5 of everyday workplace wellbeing – Window left variation

Test no. Window Pos	'1' → '5' (comfort intervals)	Very Negative '1' → Very Positive '5' (%)	Between intervals '1' → '5' (%)
7 (behind)	- 0.38 intervals	- 6.0%	- 1.50%
8 (behind)	- 1.26 intervals	- 23.3%	- 5.82%
9 (behind)	- 0.60 intervals	- 17.8%	- 4.46%

Table 6.09 Decrease in visual comfort from subjective appraisals' 1 - 5 of everyday workplace wellbeing – Window behind variation

The results from tests 1 – 3 and 7 – 9 (window front and behind respectively) supported the hypothesis although the actual weighting that general workplace appraisal had on subjective responses is limited. From these variations the average reduction in visual discomfort response level was two thirds (0.67) of a response interval. Tests 4 - 6 (perpendicular workstation) did not display these trends. This could be explained by the recurring theme of the perpendicular workstation reducing the impact of the high window luminances on visual comfort and any subsequent correlations between visual comfort and other factors. Or secondly, there is no correlation at all; however in any case the results do suggest further research may be warranted. It should also be noted that it is difficult to ascertain whether users' appraisal of workplace wellbeing in their own office would extend into the experiment office in this experiment. General workplace appraisal is a broad definition and covers many facets such as social factors (i.e. staff morale) and environmental factors (temperature, view) etc. The possible link shown in this experiment between what could be any one of those factors and visual comfort which could likely affect productivity levels is a well justified reason for further study into this particular area of discomfort/disability glare perception. While one could argue that promoting user satisfaction with their workplace in a generic sense (not just lighting) will help reduce visual discomfort (or encourage user tolerance of unsatisfactory lighting at least), are the actual benefits (while present) possibly not enough to warrant the time or money to encourage general workplace satisfaction in the first place? Further research could yield such information.

7.0 Results, Recommendations and Possible Future Research

7.1 Results and Recommendations

In general, the aim of daylighting design should be to provide a space with both *quantity* and *quality* of illumination. That is to provide the space users with a sufficient illumination level for acceptable visual performance which in the case of this experiment was quantified using the visual test, and a comfortable luminous environment to be in which was quantified using the users subjective assessment of the visual comfort levels under each condition. This sometimes elusive quality of 'visual comfort' is somewhat difficult to obtain.

"Quality of illumination is achieved when such aspects as glare limitation and the spatial distribution of flow of light are considered. There is no single daylighting design. The design chosen for a particular situation is usually a compromise based on a number of criteria. These include the functional and environmental requirements of the occupier, financial limitations, thermal, visual, acoustic and climatic considerations of the environment, and their interaction with the total concept" (Department of Productivity, 1983, p. vii).

Office layout is obviously an important factor when trying to minimize the likelihood of glare. The results from the experiment have shown across all facets measuring the impact of glare (subjective appraisal and objective test) that perpendicular workstations reduce the negative effects. Designers should be aware of the implications of workstation layout on lighting quality. While Occupational Safety & Health recommends perpendicular workstations to daylight facades, and the science behind the recommendations makes sense, there is little information available on the tangible benefits on visual comfort and productivity available for using this layout. The results from this experiment begin to quantify these benefits. It appears that the differences between visual comfort and productivity due to workstation orientations are not small, possibly statistically irrelevant quantities but noticeable and document-able figures. With further research of simulated office environments and by changing factors such as window size and orientations, this relationship could be better quantified. It could then be used to produce tables (see example table below) of recommended layouts, adaptation ratio and luminance limits as well as adaptation ratio percentage difference limits which have been shown (see graph below) to have a strong link with visual comfort (particularly when the glare source is in front of the user).

Window Position:	Ratio Limit:	% Difference Limit:	Luminance Limit:
Front	4.8:1	≥ 24.4%	2160 cd/m^2
Left	5.3:1	≥ 15.9%	2740 cd/m^2
Behind	1.7:1	≥ 48.3 %	1550 cd/m^2

Table 7.01 Example table layout of recommended maximum luminance, luminance ratios and percentage differences based on specific luminous conditions and a conservative BCD

The ratio and luminance limits here are approximate (rounded to 1dp or the nearest 10 cd/m^2 (respectively) since fluctuations smaller than this are unlikely to be noticeable to the human eye). It is important to note that the percentage difference for the window behind variation are derived from the wall:adaptation and adaptation:task ratios and is so large only because the ratios themselves are so low (which likely mitigates the impact of the relatively high variance in relation to other positions). It is interesting to conclude also that the ratio limits are actually well within established limits (e.g. 10:1) but it is the factor definitions within the ratio which are different.

Window Position:	Borderline Comfort/Discomfort Luminance	% Above Traditional 1500 cd/m^2
Front	2160 cd/m^2	44 %
Left	2740 cd/m^2	83 %
Behind	1550 cd/m^2	03 %

Table 7.02 Comparison of traditional recommended maximum luminance for visual comfort to conservative BCD luminances derived from this experiment

As expected, even using a conservative BCD definition for deriving the BCD window luminances, the figures were noticeably above traditional recommendations. With informed designing of office layouts in relation to the daylighting apertures in the space, the BCD window luminance can be as much as 80% higher than the 1500 cd/m^2 (Osterhaus, 2002) recommendation. However, if in a situation where a designer had to make a recommendation for maximum window luminances (assuming that control techniques for the window luminance were available) and had no knowledge of likely workstation layout or window positions then the traditional 1500 cd/m^2 is still a good conservative figure based on these results.

A productivity impact summary is below (comprehensive results can be found in section 4.0). It could be of particular use to employers as a breakdown of likely impacts on certain window or workstation layouts in their offices on productivity (reading comprehension and screen scanning accuracy).

Window Position:	Productivity Type	Average ↑↓ in Productivity
Front	Errors (Landolt rings)	+1.03 slits
	Accuracy (letter count)	+0.30 away from correct no.
	Duration	+2.47 seconds
Side	Errors (Landolt rings)	+0.58 slits
	Accuracy (letter count)	+0.35 away from correct no.
	Duration	+1.67 seconds
Behind	Errors (Landolt rings)	+2.80 slits
	Accuracy (letter count)	-0.19 away from correct no.
	Duration	+3.5 seconds

Table 7.03 Summary of effects of window position on productivity factors

It is important to note that these were for short-term exposure tests (1 – 2mins) and the figures would need to be multiplied out by an entire working day to represent likely real world office effects. The small numbers for short-term exposure could actually result in large differences over an eight hour working day for example (reading comprehension = letter count, scanning accuracy = Landolt rings).

7.2 Future Research

The results shown below graphically illustrate the variance between the adaptation luminances (the window behind variation uses “wall to adaptation” rather than “window to adaptation”) as window luminance was increased. The importance of this increasing difference in the two adaptation ratios could be better established with further testing (more layouts, window sizes or with a direct focus on testing small and large ratio differences or much higher than BCD luminances whilst trying to keep the adaptation ratios percentage difference low).

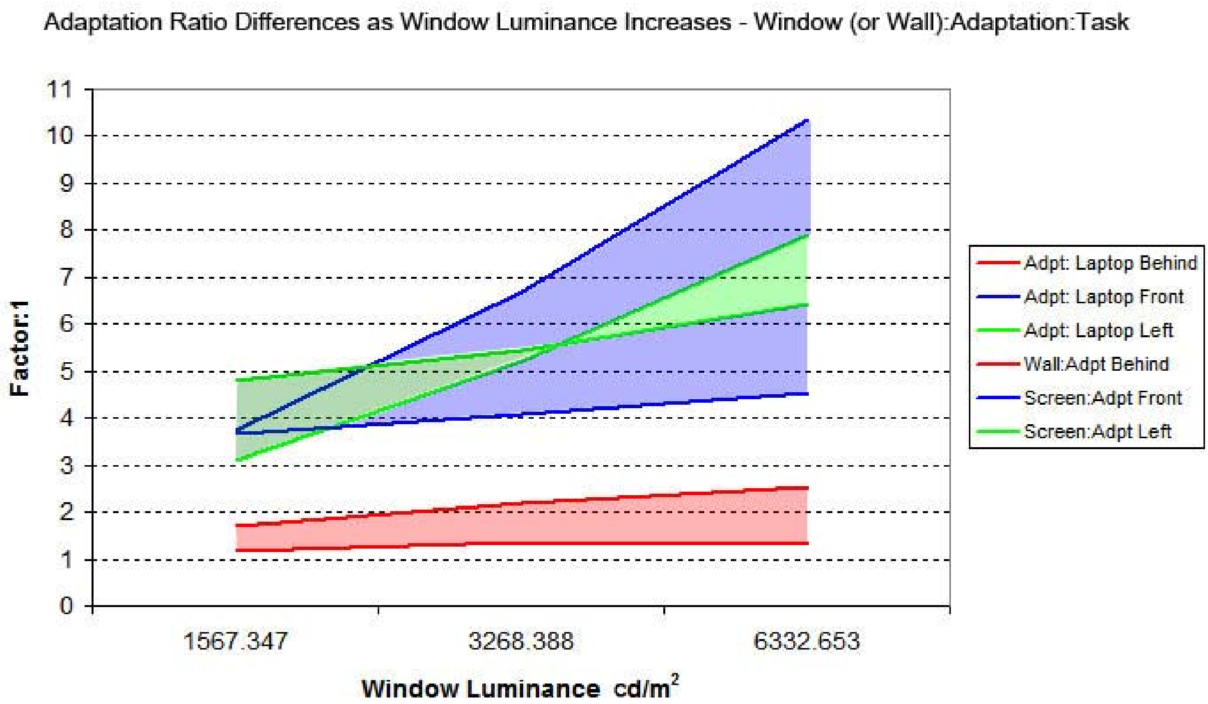


Figure 7.01 Adaptation Ratio Variances for each window variation

Results from the experiment also raise the question of whether one type of glare (discomfort or disability) infers the other? Conditions designed to cause either a decline in productivity or comfort was observed to affect both. It may be that conditions typically associated with disability glare (veiling reflections) also reduce comfort by requiring the visual system to work harder to distinguish characters and maintain efficiency. The same could possibly be said about conditions usually associated with discomfort glare. If an unshielded luminance in the field of view is sufficient to cause discomfort it may be hindering the visual system’s ability to process information thereby negatively affecting productivity. Further research of visual test performance in relation to subjective visual comfort assessments of the lighting conditions (situations designed specifically to cause one type of glare or other) could help conclude the comparative effects of disability glare on discomfort glare effects and vice versa. This research suggests small reductions in productivity, result in relatively larger reductions in comfort which is intuitively hard to make sense of since productivity and lighting conditions are normally tied to *disability* glare, *not* discomfort glare. Whether or not it is in fact sensible to distinguish between the two types of glare or if one simply infers the other, could also be a result of further research into this specific area.

No significant gender effects were found from the results, which is consistent with the literature (the gender results themselves can be found in Appendix four). Although age may have some impact on appraisal of lighting conditions, a significant effect was not found in this experiment. This is due to the distribution of the age of test subjects being weighted towards the younger demographic where intuitively one can expect no significant age effects (the age results can be found in appendix four). Further research into age effects could be undertaken by testing two large enough test groups consisting of one with 'young' and one with 'old' subjects. The information from an experiment of this nature would be useful as it attempts to identify how as users go through their working age life, what impact this has on sensitivity to glare. It could help employers and lighting designers by suggesting how careful they need to be with glare reduction based on the likely age of the spaces end-users and hopefully give an end to the question of how strong the effects of age are on the sensitivity to glare.

Some of the other results from the user-survey produced interesting results with regards to the impact of glare on different user groups. However, further testing especially in the areas identified in this experiment (see section 7.0) could help establish if the differences are very real and if they are in fact significant or not worth factoring into specific user-based daylighting design recommendations. An end product of this type of research might be a set of guidelines suggesting how important glare prediction is based on the specific characteristics of the users occupying a space. The survey data in its entirety can be found in Appendix four which contains information on all the factors which were documented. One or more of the unanalysed factors from the user survey may prove to be a contributing factor to overall sensitivity in different users to glare. The researcher in no way suggests the characteristics considered in this experiment are the only ones which could affect glare sensitivity in users. Further research, considering all the survey information collected, may yield interesting results on other user group sensitivities to glare and the researcher encourages this to be done.

Results from the experiment suggest that the letter 'W' is simply easier to find than the other letters used in the letter count (possibly due to its shape or size). The letter count results from this part of the test are at odds with subjective assessments and Landolt ring results from the same tests, relative screen contrasts and results from the other positions where different letters were being counted. There may of course be no more difficulty in locating a 'W' than any of the other letters and for an unknown reason, users' ability to locate specific characters increases when the glare source is behind the user. It may be better from an experimental design viewpoint to always count the same letter to mitigate these possible differences although this introduces another potential problem of subjects 'learning' to identify the letter more efficiently over time and having prior awareness of their target. In any situation, further testing is required before conclusive reductions/increases in reading comprehension for this position could be documented.

8.0 Conclusion

It would seem that luminance limits for visual comfort are in fact beyond what current recommendations might suggest; at least in daylit spaces where the daylight aperture has a large impact on adaptation levels. Adaptation levels and luminance ratios, especially the difference between the two adaptation ratios (discussed in section 7.2) appear to have a profound link to visual comfort levels although the ratios themselves were all typically within established ratio limits. It is important to note that those ratio limits were originally between different factors (task area and glare source). This supports the theory that it is not the ratios but simply the definitions of the factors the ratios are between which might need changing. In order to account for adaptation effects, one of the factors should be a value, which incorporates the impact of both direct and reflected luminances in the users' field of view on their sensitivity to various luminance distributions (this factor is discussed in sections 2.4 and 7.0). Currently, the two ratio factors "task" and "glare source" luminance do not account for this as the more comprehensive indices do which limits their widespread and reliable application.

So the information, at least in its infancy, is there but the difficulty comes in trying to encourage office users and designers to employ the recommendations or design tools. As Einhorn (1998) suggests, one of the ways to encourage the practical implementation of glare-reduction design recommendations is to make the process of calculating, finding or using them as simple as possible to follow. Glare indices can be an effective tool for the prediction of glare in a wide variety of situations because they account for the key factors (solid angle, position of glare source, glare source luminance and background or adaptation luminance) but they require an understanding of both the software and the scientific terms to be useful to the designer. Luminance ratio recommendations are a relatively quick and easy technique for prediction of glare but lack information on the likely severity or impact of the glare source's position. By refining the understanding of the impact of different glare source positions or sizes, the usefulness of luminance ratio recommendations is improved. If designers are given a simple matrix of recommended luminance ratios tailored to the luminous conditions likely to be present in a final design, then a prediction on glare likelihood based solely on relatively easy to understand information e.g. just the field of view luminance values from a pre-rendered image containing the high dynamic range of data for each pixel can be made.

Ratios currently being recommended are based on research conducted in an era of typically completely different luminous environments with predominately incandescent sources as the norm and smaller window sizes in offices. This limits the reliability of the prediction for the likelihood of glare. As demonstrated in this experiment, window luminances produce ratios far in excess of these limits but the impact of adaptation levels because of the large effect of the window on the overall illumination levels, not to mention the intangible quality and immeasurable effect of the 'view factor' could mitigate the negative aspects of these high ratios.

Although the effect a pleasant view may have on subjective glare assessment is very difficult to quantify or even test for, the other factors such as luminance distribution (based on window size, position etc) can be quantified. This is what was attempted in this study. It can be said with a reasonable degree of certainty based on both overall subjective appraisal of the lighting conditions and the comparative effects on productivity levels, that workstations placed perpendicular to daylighting facades are certainly beneficial. Occupational Safety and Health already recommends this, but with no discussion on the specific benefits for comfort and productivity. This study has proven useful by quantifying likely benefits.

Higher adaptation levels resulting from having large area glare sources have been suggested as a contributing factor to the difficulty of adhering to older ratios. It may even be unnecessary to adhere to these older ratios. Specifying ratios between task area and glare source is unlikely to give an accurate prediction of the likelihood of glare in a daylit office as the task luminance is often lower than the adaptation luminance level which is one of the strong factors dictating how noticeable a glare source is. However there may be more to the science of glare prediction from luminance ratios than merely keeping an adaptation ratio within a 10:1 or 40:1 limit. The results from this experiment suggest that adaptation luminance should be used as an intermediate factor between task and glare source luminance and it is the difference in these ratios which can affect the likelihood of glare (not to mention, the position of the window which was a strong factor in this experiment). By designing offices with luminous conditions for which the variance in the ratios is small (i.e. the ratios of glare source to adaptation and adaptation to task luminance are similar), the designer attempts to ensure that the adaptation level is not too low for the glare source (window) and not too high for the task area (VDU, desk area).

Difficulties also arise with keeping adaptation ratio differences as low as possible or comparing them to a recommended limit because different layouts (and possibly window sizes) affect the difference as well as the impact of that difference (i.e. the same percentage difference in two different layouts impacts users to different degrees). For this reason it is important to make luminance ratio recommendations (regardless of the factors used in their definition) specific to user position, office layout and glare source size. With basic knowledge of the building design, the use of rendering software capable of producing luminance and illuminance values, and a database of recommended maximum field of view luminances, luminance ratios and differences between ratios, architects, interior designers and lighting designers alike can make relatively quick predictions of the likelihood of glare even if they have a limited understanding of the factors affecting this likelihood.

The results from these or similar experiments can also be used to increase the power of programs like FINDGLARE which assigns arbitrary ratios or luminance thresholds for finding potential glare sources but which we now know to be an inefficient method as the ratio and impact of specific luminances vary greatly depending on the specific characteristics of the luminance distribution and workstation/office layout. FINDGLARE is also a versatile enough tool which would allow a designer to use it to calculate adaptation ratios based on the illumination of a surface placed within the scene at the vertical plane of the user's eye. This could then be used to calculate adaptation luminance and subsequently the ratios and difference between this factor and glare-source/task luminance. Equipped with the ratios percentage difference, a list of recommended maximum ratios and with an understanding of how the chosen office layout and all the other factors affect specific types of users' glare perception, the architect, interior or lighting designer can make glare predictions based on present-day experiments and the specific characteristics of the office space. A summary of the basic preliminary recommendations (for ratios, ratio differences, office layouts etc) are:

- Simplicity has been suggested as an important factor to the successful implementation of any design recommendations. Designers and especially everyday space users should be given a simple set of instructions identifying what and where luminance values should be recorded and what layouts should be used if possible. This will maximise the likelihood of successful implementation.
- Rather than specifying maximum ratios between task area and glare source, the ratio should incorporate an intermediate adaptation luminance value. This is to account for the impact of all the light in the field of view on users' perception of a window or large area luminance as a glare source. The ratios themselves should vary depending on the likely office layout and luminance distribution. The maximum ratios for different office layouts can be found in section 7.0.
- The percentage difference of the ratios between the large glare source luminance and adaptation luminance and the adaptation and task area luminance should be kept as small as possible. This is to ensure that the adaptation levels are not too low for the glare source or too high for the task area. For example, if adaptation (using relative values) was a '5' and glare source luminance was recorded as a '25' (a 25:5 or 5:1 ratio) then task area luminance should be as close to '1' as possible (a 5:1 ratio). The maximum percentage differences for different office layouts can be found in section 7.0.
- Workstations should be placed perpendicular to daylight apertures. Results from this experiment support previous recommendations regarding workstation positions.
- Before glare prediction is begun, the designer should be given an outline of the main characteristics of the likely space users. The results from the user survey suggested users with certain characteristics could be more or less sensitive to glare.

The results could be used by designers and employers alike, e.g.:

- Addressing spaces already built where the aim is to identify the factors causing poor visual comfort due to
    - poor workstation layout relative to daylight apertures, or

- luminances in excess of comfort thresholds for that specific office layout, or
- too large differences in adaptation ratios

- Identifying the types of employees who could benefit from improved lighting conditions - a benefit, not just in visual comfort terms but also productivity terms which is desirable from an employer standpoint

- Pre-construction assessment of the likelihood of glare assessed via models of the space for
  - testing the impact of different window sizes, positions, orientations or different workstation positions, etc and
  - comparisons of different daylighting design strategies.

Providing more accurate data on the likelihood of glare while a building is still in the design phase and changes are relatively cheap to implement is preferable to costly retrofits or compromising a design by adding in after-thoughts, e.g. blinds (which also inhibit the intangible 'view factor'). Couple the improved likelihood of visual comfort with productivity benefits which in many cases represents an economic or bottom-line figure to employers, and skilled lighting designers using contemporary ratio and ratio-difference limits for space specific recommendations and glare prediction could well be in high demand in the future. Also, in comparison to the relatively more complicated glare prediction indices involving various factors and calculations, luminance ratio recommendations are an easy to understand tool which with further study could become a simple yet powerful method for site-specific and even user-specific glare prediction in the future.

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- **Figures 2.03 – Figure 2.04 Photos of the artificial window used in the experiment with and without the additional curtain fabric covering the pedestal and sides. Source:** Linney, A. (2007). *Maximum Luminances and Luminance Ratios and their Impact on Visual Comfort and Productivity in Offices.* School of Architecture, Victoria University of Wellington, NZ.
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- **Figure 2.16 Colour scale used for luminance distributions of artificial window at each setting. Source:** Linney, A. (2007). *Maximum Luminances and Luminance Ratios and their Impact on Visual Comfort and Productivity in Offices.* School of Architecture, Victoria University of Wellington, NZ.
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- **Figure 2.23 Subjective Assessment Scale used by users in experiment. Source:** Linney, A. (2007). *Maximum Luminances and Luminance Ratios and their Impact on Visual Comfort and Productivity in Offices.* School of Architecture, Victoria University of Wellington, NZ
- **Figure 2.24 User survey page:** Linney, A. (2007). *Maximum Luminances and Luminance Ratios and their Impact on Visual Comfort and Productivity in Offices.* School of Architecture, Victoria University of Wellington, NZ
- **Figure 2.25 Example of study results showing links between user characteristics, lighting conditions and task performance. Source:** Pistor, K., Von Neida, W., Chow, W., Boyce, P., Rea, M. (2001). *'Lighting and Human Performance II – Beyond Visibility models towards a Unified Human Factors Approach to Performance'* Electric Power Research Institute Inc.
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11.0 Glossary

Some Terminology from http://www.schorsch.com/kbase/glossary/ (author: Georg Mischler, Dipl. Arch. ETH)

- **Luminance:** "is the photometric measure of 'brightness'" (Moore, 1986, p. 3 - Full paper). It is measured in candelas per square meter (Cd/m^2). 'Reflected luminance' is a product of the illumination of an opaque surface and is "analogous to the water bounced off of a sponge" (ibid)
- **Brightness:** The subjective interpretation/perception of luminance (usually a product of both luminance and adaptation levels of the eye).
- **Illuminance:** The amount of light reaching a specific point on a plane (real or imaginary). It would be analogous to the amount of water being poor onto a sponge and is measured in 'Lux' or lumens per square meter (lm/m^2).
- **Luminous Intensity or Candela:** The luminous intensity per unit solid angle (see section 1.2 for detailed definition). Originally based upon the light output of a standardized candle (e.g. a standard candle emitted one candela per steradian although in recent times the 'candela' has been given a more specific radiation frequency).
- **Luminous flux or Lumen:** If a point light source with a luminous intensity of one candela were placed inside an imaginary sphere then every 1 m2 of that sphere would receive 1 lumen.
- **Lux**: A term which is simply short for 'lumens per square meter'
- **Reflectance:** "the ratio of incident luminous flux upon a surface which is reradiated in the visual spectrum" [ ] "Unit of reflectance is percent (%) or a factor between 0 and 1".
- **Adaptation:** "1. The process by which the visual system changes its sensitivity, depending on the *luminances* prevailing in the visual field. The system becomes accustomed to processing higher or lower light levels in its environment than it was exposed to before. In a quick first step, some change is achieved by increasing or reducing the iris opening (in photographic terms: the *aperture*), which directly increases or reduces the amount of light that can enter the eye. In a second step, the receptive cells on the retina of the eye change their actual sensitivity. The latter is a slower process, so that it may take a few minutes until the visual system is fully adjusted to the new situation. Since there are several types of receptive cells in the eye, which are sensitive to different bands in the visible spectrum, the adaptation also manages the "*white balance*" of the eye, by chromatic adaptation. If the new lighting situation has a different *colour temperature*, e.g. there is an increased amount of red light relative to the total amount of light, then the cells responsible for sensing red light will reduce their sensitivity relative to the sensitivity of the other cells. As a result, a white surface will again appear white to the observer after a certain time, although it reflects a proportionally increased amount of red light. A very obvious example of (quantitative)

adaptation can be observed by a person walking from full sunshine into a building. The environment in the building will appear almost pitch black at first. A few minutes later, the person can again distinguish details (eg. read text from a piece of paper). But by then, viewing out of the window will have become uncomfortable, since the proportionally very high luminance levels outside will cause strong *glare*.

2. A specific state of eye sensitivity resulting from this process. **Transient Adaptation** is a special case, where the human eye has to adapt from low to high light levels and back in short intervals. This happens when the visual environment has very high *contrasts*, eg. a computer monitor (< 200 cd/m^2) and a sunlit wall outside a window (> 5'000 cd/m^2) can be seen next to each other without turning the head. Excessive transient adaptation soon results in eye fatigue."

- **Transmittance:** is the ratio of the total *radiant* or *luminous flux* transmitted by a transparent object to the incident flux, usually given for normal incidence.

Equipment:

- Hagner Universal S2 Photometer: A camera-like device which measures 'luminance' (or numeric brightness) of a surface in the field of view (relative to its position) by looking at the surface through a view-finder (see images in section 2.6).
- Minolta T1 Light-Meter: This measures the illuminance at a point in whichever plane the sensor is placed in (whether real or imaginary e.g. a wall or a point in space).
- Artificial Window: A wooden box (see detailed description in section 2.2) containing fluorescent tubes in a uniform array; housed behind a white translucent acrylic panel. The interior wood component is painted white to maximise internal surface reflectances.
- Effulger: A small square room (see detailed description in section 2.2) in which the experiment was conducted.
- Laptop: A Dell™ 'Latitude D505' with adjustable screen luminance.
- Computer chair: Typical office chair with adjustable height.
- Computer table: Dark (low reflectance) table on castor wheels to allow table to be moved into different positions during the tests.
- Camera tripod: Typical camera tripod used to ensure Hagner photometer measurements were always taken from the same position (since position could affect luminance measurements).
- Colorimeter: Used to measure the reflectance of the Effulger walls. It outputs three pieces of data: the surface reflectance, and an x and y value which correspond to a particular colour. Also useful in rendering packages where surface definitions are given with RGB and reflectance values.

APPENDIX ONE:

CALCULATIONS

Window in Front Variation - Borderline Comfort/Discomfort

Equation for line of best fit of overall subjective assessment:

$Y = 1.6042X + 0.8264$

Rearranged for X to be the subject

$X = (Y - 0.8264)/1.6042$

BCD value ('Y') of '3' substituted into formula

$X = 1.35$

Calculate BCD ('X') window luminance (lowest setting ('1') + proportion of difference between this value and middle setting '0.35')

$X = 1567.35 + 0.35 \times (3268.39 - 1567.35)$

BCD Window Luminance (Front) = 2162.7 Cd/m^2

Window in Front Variation - Adaptation Luminance

Equation for calculating approximate adaptation luminance:

Adaptation Luminance = Vertical Illumination at the eye (E_v) / π

Substitute in recorded values for E_v

Lowest Setting	**$1349 / \pi = 429.62$ cd/m^2**
Middle Setting	**$2520 / \pi = 802.55$ cd/m^2**
Highest Setting	**$4390 / \pi = 1398.1$ cd/m^2**

Window in Front Variation - BCD Adaptation Luminance % Difference

Use same method as for calculating BCD luminance but using recorded adaptation luminances at lowest and middle window settings

BCD Adapation Luminance = 429.62 + 0.35 x (802.55 - 429.62)

BCD Adaptation Luminance = 560.15 Cd/m^2

Calculate likely task area luminance with same method

BCD Task area luminance = 115 + 0.35 x (120 - 115)

BCD Task area luminance = 116.75 Cd/m^2

Use BCD window luminance, BCD adaptation luminance and BCD task area luminance to calculate adaptation ratios

Window Luminance / Adaptation Luminance

2162.7 / 560.15 = 3.86

3.86 : 1 (window luminance : adaptation luminance)

Adaptation Luminance / Task area luminance

560.15 / 116.75 = 4.80

4.80 : 1 (adaptation luminance : task area luminance)

Glare soure is 3.86 times brighter than adaptation level and task area is 4.80 times dimmer than adaptation level

% Difference = (higher value - lower value) / lower x 100%

% Difference = (4.80 - 3.86) / 3.86 x 100

% Difference = 24.35%

Window 90° Left Variation - Borderline Comfort/Discomfort

Equation for line of best fit of overall subjective assessment:

$Y = 1.1146X + 1.1111$

Rearranged for X to be the subject

$X = (Y - 1.1111)/1.1146$

BCD value ('Y') of '3' substituted into formula

$X = 1.69$

Calculate BCD ('X') window luminance (lowest setting ('1') + proportion of difference between this value and middle setting '0.69')

$X = 1567.35 + 0.69 \times (3268.39 - 1567.35)$

BCD Window Luminance (Left) = 2741.07 Cd/m^2

Window 90° Left Variation - Adaptation Luminance

Equation for calculating approximate adaptation luminance:

Adaptation Luminance = Vertical Illumination at the eye (E_v) / π

Substitute in recorded values for E_v

Lowest Setting	1025 / π = 326.43 cd/m^2
Middle Setting	1880 / π = 598.73 cd/m^2
Highest Setting	3100 / π = 987.26 cd/m^2

Window 90° Left Variation - BCD Adaptation Luminance % Difference

Use same method as for calculating BCD luminance but using recorded adaptation luminances at lowest and middle window settings

BCD Adapation Luminance = 326.43 + 0.69 x (598.73 - 326.43)

BCD Adaptation Luminance = 514.32 Cd/m^2

Calculate likely task area luminance with same method

BCD Task area luminance = 105 + 0.69 x (115 - 105)

BCD Task area luminance = 111.9 Cd/m^2

Use BCD window luminance, BCD adaptation luminance and BCD task area luminance to calculate adaptation ratios

Window Luminance / Adaptation Luminance

2741.07 / 514.32 = 5.33

5.33 : 1 (window luminance : adaptation luminance)

Adaptation Luminance / Task area luminance

514.32 / 111.9 = 4.60

4.60 : 1 (adaptation luminance : task area luminance)

Glare soure is 5.33 times brighter than adaptation level and task area is 4.60 times dimmer than adaptation level

% Difference = (higher value - lower value) / lower x 100%

% Difference = (5.33 - 4.60) / 4.60 x 100

% Difference = 15.87%

Window Behind Variation - Borderline Comfort/Discomfort

Equation for line of best fit of overall subjective assessment:

Y = 1.5938X + 1.4236

Rearranged for X to be the subject

X = (Y - 1.4236)/1.5938

BCD value ('Y') of '3' substituted into formula

X = 0.99

Calculate BCD ('X') window luminance (lowest setting ('1') x proportion of lowest setting which represents BCD ('0.99')

X = 1567.35 + 0.69 x (3268.39 - 1567.35)

BCD Window Luminance (Behind) = 1550.24 Cd/m^2

Window Behind Variation - Adaptation Luminance

Equation for calculating approximate adaptation luminance:

Adaptation Luminance = Vertical Illumination at the eye (E_v) / π

Substitute in recorded values for E_v

Lowest Setting	**810 / π = 257.96 cd/m^2**
Middle Setting	**1370 / π = 436.31 cd/m^2**
Highest Setting	**2390 / π = 761.15 cd/m^2**

Window Behind - BCD Adaptation Luminance % Difference

Calculate BCD Adaptation luminance using lowest recorded adaptation luminance x proportion of lowest setting which represents BCD (0.99)

BCD Adapation Luminance = 257.96 x 0.99

BCD Adaptation Luminance = 255.38 Cd/m^2

Calculate likely task area luminance with same method

BCD Task area luminance = 150 x 0.99

BCD Task area luminance = 148.5 Cd/m^2

Calculate likely wall luminance with same method

BCD Wall luminance = 300 x 0.99

BCD Wall luminance = 297.0 Cd/m^2

Use BCD window luminance, BCD adaptation luminance, BCD task area luminance and wall luminance to calculate adaptation ratios

Window Luminance / Adaptation Luminance

1550.24 / 255.38 = 6.07

6.07 : 1 (window luminance : adaptation luminance)

Adaptation Luminance / Task area luminance

255.38 / 148.5 = 1.72

1.72 : 1 (adaptation luminance : task area luminance)

Wall Luminance / Adaptation Luminance

297.0 / 255.38 = 1.16

1.16 : 1 (wall luminance : adaptation luminance)

Glare soure is 6.07 times brighter than adaptation level and task area is 1.72 times dimmer than adaptation level

% Difference = (higher value - lower value) / lower x 100%

% Difference = (6.07 - 1.72) / 1.72 x 100

APPENDIX TWO:

SUBJECTIVE ASSESSMENT RESULTS

Subjective Assessments 1 -7

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
User 1	3	2	6	5	2	3	5	6	7
User 2	3	3	5	1	2	7	2	5	7
User 3	5	5	7	2	2	3	3	4	6
User 4	2	5	7	3	5	7	3	5	6
User 5	2	6	7	2	2	5	2	3	4
User 6	4	6	7	4	5	7	4	7	7
User 7	3	5	6	2	4	5	1	3	6
User 8	3	4	7	2	2	6	2	4	6
User 9	5	5	5	3	3	4	5	5	6
User 10	5	3	7	3	4	5	3	4	6
User 11	1	5	4	1	4	2	2	3	5
User 12	4	5	6	4	3	5	5	4	7
User 13	2	5	6	2	6	6	3	6	7
User 14	1	3	5	1	2	4	2	4	7
User 15	1	6	7	1	2	6	2	7	7
User 16	6	6	7	2	4	4	2	4	7
User 17	2	4	4	2	4	5	5	6	6
User 18	3	2	7	1	2	5	6	7	7
User 19	1	2	6	1	3	6	2	3	7
User 20	2	3	6	2	3	5	2	4	5
User 21	3	4	7	2	2	3	3	5	7
User 22	2	2	3	3	3	4	3	5	7
User 23	1	2	5	5	5	6	3	6	7
User 24	4	5	7	3	4	6	4	5	7
User 25	1	2	5	1	1	3	2	2	5
User 26	3	5	6	5	5	6	4	7	7
User 27	1	3	6	2	4	3	3	5	6
User 28	1	2	5	1	3	2	2	3	5
User 29	3	5	2	4	3	2	5	6	7
User 30	3	5	7	2	2	3	2	5	6
User 31	3	5	7	3	3	6	4	6	7
User 32	3	7	7	4	5	7	3	5	7
User 33	2	4	7	2	2	5	3	2	5
User 34	2	3	6	2	3	5	3	2	7
User 35	3	4	7	3	2	5	4	6	7
User 36	5	6	7	4	6	7	6	7	7
User 37	1	1	2	1	1	2	1	3	5
User 38	2	5	7	3	5	7	4	7	7
User 39	2	3	6	1	3	5	2	3	6
User 40	2	5	4	2	3	3	2	6	7
User 41	3	3	6	3	2	5	5	5	7
User 42	2	1	6	1	2	3	3	5	4
User 43	2	4	7	4	5	5	3	4	4
User 44	2	3	4	1	3	2	1	3	5
User 45	1	1	3	1	1	1	1	1	5
User 46	1	2	3	1	2	3	1	3	5
User 47	3	6	7	2	3	5	4	6	7
User 48	2	2	4	2	3	5	3	4	6
Average	2.520833	3.854167	5.729167	2.333333	3.125	4.5625	3.020833	4.604167	6.208333
S.D	1.271447	1.58436	1.469398	1.208715	1.298526	1.623055	1.328727	1.55385	0.966642
Max	6	7	7	5	6	7	6	7	7
Min	1	1	2	1	1	1	1	1	4

APPENDIX THREE:

VISUAL TEST RESULTS

Subject no:1 1 **Key:** **1 = Did not locate inside 4 second time frame** **Time = Test duration (seconds)**

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9		17		23		30		24		19	1	23	
3	4		30		14		20		27		8		9		3		17	
4	14		10	1	23		7		6		1		23		31	1	2	1
5	17		19		17		30		10	1	16		18		20		28	
6	21		28		28		5		29		12		6		4	1	18	1
7	29		12		24		29		15		24	1	29		22	1	6	
8	12		21		10		6		18		14	1	2		16	1	24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5	1	21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22	1	32		11		21	1
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8	1	15	
Time:	33		39		33		32		37		42		35		42		45	
Letter count:	N = 18	18	N = 16	16	N = 19	18	R = 17	17	R = 23	23	R = 17	17	W= 18	18	W= 19	19	W= 20	22
Time:	56		48		62		50		51		47		40		42		48	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10	1	14		10		8		32		26	
19	23		22		18	1	4		9		23		27		10	1	1	
20	5	1	16		5		12		28		7		11	1	26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4	1	15		5		17		7		18	1	12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21	1	5	
25	28		11		21		13		13		20		22	1	2	1	22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6	1	2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6	1	27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19		19	1	28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11	1	12		1		30	
Time:	38		35		49		36		39		38		42		39		40	
Errors:	1		1		3		1		1		5		3		12		5	

Subject no:2 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9		17		23		30		24		19	1	23	
3	4		30	1	14		20		27		8		9	1	3		17	
4	14		10		23		7		6		1		23	1	31	1	2	1
5	17		19		17	1	30		10		16		18		20		28	1
6	21	1	28		28		5		29		12		6		4		18	
7	29		12		24	1	29		15		24	1	29		22	1	6	1
8	12		21		10	1	6		18		14	1	2		16		24	1
9	15		15		22		18		21		26		28	1	5		29	
10	10	1	31	1	7	1	16		12		5		21	1	14		9	1
11	24		9		15		9		25		13		13	1	30		13	1
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30	1	28		17		7		32	
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32		11	1	31		2		10		27		3	
16	25		20		29	1	21		11		15		26		8		15	1
Time:	52		45		50		48		42		46		49		55		55	
Letter count:	N = 18	15	N = 16	15	N = 19	14	R = 17	15	R = 23	15	R = 17	15	W= 18	18	W= 19	19	W= 20	20
Time:	82		90		90		57		45		64		85		50		65	
17	20		18		11		27		22		18	1	15		15	1	31	
18	16		29	1	2		10		14		10	1	8		32	1	26	
19	23		22		18		4		9		23		27		10	1	1	
20	5		16	1	5		12		28		7		11		26		7	1
21	7		3		20	1	26		19		29		31	1	23		19	1
22	22		27		4	1	15		5		17		7		18		12	
23	31	1	2		13	1	28		8		3		14	1	13		14	
24	8		14		31	1	1		26		9	1	30	1	21	1	5	1
25	28		11		21		13	1	13		20	1	22		2		22	1
26	11		24		25	1	24		4		27		16		9	1	16	1
27	27		8		6		2		24		6		4		29	1	4	1
28	13	1	17		27		19		16		31	1	20	1	6		27	1
29	2		23		16		25		32		4	1	25		24		10	1
30	32	1	4		1		23		1		19		19		28	1	20	
31	30		32		12	1	8		20		32		3	1	17	1	25	1
32	1		26		8		31		3		11		12		1	1	30	
Time:	52		52		55		45		48		55		46		50		57	
Errors:	5		4		11		2		1		8		10		14		17	

Subject no:3 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9	1	17	1	23		30		24		19	1	23	
3	4		30		14	1	20		27		8		9		3		17	1
4	14		10		23	1	7		6		1		23		31		2	
5	17		19		17	1	30		10		16		18		20		28	1
6	21		28		28	1	5		29		12		6	1	4		18	
7	29		12		24	1	29		15		24		29		22		6	1
8	12		21		10	1	6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5	1	29	
10	10		31	1	7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30	1	13	
12	6		13	1	19	1	32		2		21	1	5		12		8	1
13	26		6		3	1	3		30		28		17		7		32	1
14	18		1	1	26		14		7	1	22		32		11		21	1
15	9		25		32		11		31		2		10		27		3	
16	25		20		29	1	21	1	11		15		26		8		15	
Time:	50		44		65		44		39		52		52		47		53	
Letter count:	N = 18	16	N = 16	15	N = 19	16	R = 17	15	R = 23	21	R = 17	15	W= 18	17	W= 19	19	W= 20	17
Time:	48		41		53		41		51		43		48		58		47	
17	20		18		11		27	1	22		18		15		15		31	
18	16	1	29		2	1	10		14	1	10		8	1	32		26	
19	23		22		18		4		9		23		27		10		1	1
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29	1	31		23		19	
22	22		27		4		15		5		17		7		18		12	1
23	31		2		13	1	28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28	1	11	1	21	1	13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	1
27	27	1	8	1	6		2		24	1	6		4		29		4	1
28	13		17		27	1	19		16		31		20		6	1	27	1
29	2		23	1	16	1	25		32		4		25		24		10	1
30	32	1	4		1	1	23	1	1		19		19		28		20	
31	30		32		12	1	8		20		32		3		17		25	
32	1		26		8		31	1	3		11		12		1		30	
Time:	51		55		62		46		45		48		58		60		57	
Errors:	4		6		17		5		3		2		2		4		12	

Subject no:4 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19	1	7		30		22	1	17		25		1		25		11	1
2	3		5	1	9	1	17		23	1	30	1	24	1	19		23	
3	4	1	30		14		20		27		8	1	9	1	3	1	17	
4	14	1	10	1	23	1	7	1	6	1	1		23	1	31		2	
5	17		19	1	17	1	30		10	1	16	1	18		20		28	1
6	21		28		28	1	5		29		12	1	6		4	1	18	1
7	29		12		24	1	29	1	15		24		29		22	1	6	1
8	12	1	21	1	10	1	6	1	18		14	1	2		16		24	1
9	15	1	15	1	22	1	18		21	1	26	1	28		5		29	
10	10	1	31		7	1	16		12	1	5		21		14		9	1
11	24		9		15	1	9		25		13	1	13	1	30		13	1
12	6	1	13	1	19	1	32	1	2		21		5		12	1	8	1
13	26	1	6	1	3	1	3		30	1	28	1	17	1	7	1	32	
14	18		1		26		14		7	1	22	1	32		11		21	1
15	9	1	25	1	32	1	11		31		2		10		27	1	3	
16	25		20	1	29	1	21	1	11		15		26	1	8		15	
Time:	50		55		60		43		52		53		45		50		58	
Letter count:	N = 18	17	N = 16	16	N = 19	16	R = 17	15	R = 23	21	R = 17	17	W= 18	18	W= 19	18	W= 20	20
Time:	65		55		60		55		53		69		49		58		59	
17	20	1	18		11	1	27		22	1	18		15		15		31	1
18	16		29	1	2	1	10		14		10		8		32	1	26	
19	23	1	22	1	18	1	4		9		23	1	27		10	1	1	1
20	5		16	1	5	1	12		28	1	7	1	11	1	26		7	1
21	7		3	1	20	1	26		19		29	1	31		23	1	19	
22	22	1	27	1	4	1	15		5		17		7		18		12	1
23	31		2		13	1	28	1	8	1	3	1	14		13		14	
24	8	1	14	1	31	1	1		26		9	1	30		21		5	
25	28		11	1	21	1	13		13	1	20	1	22		2		22	
26	11	1	24	1	25	1	24	1	4		27		16		9		16	
27	27	1	8		6	1	2		24		6	1	4		29	1	4	1
28	13		17		27		19	1	16		31	1	20		6		27	1
29	2		23		16		25	1	32		4	1	25	1	24	1	10	1
30	32	1	4		1		23	1	1		19	1	19		28		20	
31	30	1	32	1	12	1	8	1	20		32		3	1	17		25	1
32	1		26		8	1	31		3		11	1	12		1	1	30	1
Time:	48		53		65		52		63		58		46		54		53	
Errors:	17		18		26		12		11		20		9		12		18	

Subject no:5 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27	1	8		9		3		17	
4	14		10		23		7		6		1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10	1	6		18		14		2		16		24	
9	15		15		22		18		21		26		28	1	5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	
13	26		6		3	1	3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	1
15	9	1	25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	1
Time:	35		41		43		31		32		33		34		37		45	
Letter count:	N = 18	17	N = 16	11	N = 19	15	R = 17	13	R = 23	18	R = 17	12	W= 18	16	W= 19	17	W= 20	20
Time:	35		34		37		40		47		44		39		44		51	
17	20		18		11	1	27		22		18		15		15	1	31	
18	16		29		2		10		14		10		8		32		26	
19	23		22	1	18		4		9		23		27		10	1	1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20	1	26		19		29		31		23		19	1
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	1
24	8	1	14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	1
26	11		24	1	25		24		4		27		16		9		16	
27	27		8		6	1	2		24		6		4		29	1	4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	38		100		50		29		34		39		42		47		49	
Errors:	2		2		5		0		1		0		1		3		9	

Subject no:6 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	37		60		40		37		45		38		37		43		48	
Letter count:	N = 18	18	N = 16	15	N = 19	17	R = 17	17	R = 23	22	R = 17	14	W= 18	16	W= 19	19	W= 20	20
Time:	48		45		65		39		52		47		37		52		44	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10	1	8		32		26	
19	23		22	1	18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28	1	8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13	1	20		22		2		22	
26	11		24		25		24		4		27		16		9	1	16	1
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24	1	10	1
30	32		4	1	1		23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	44		65		52		44		46		49		41		65		72	
Errors:	0		2		0		1		1		1		0		4		5	

Subject no:7 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19	1	17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14	1	9	1
11	24		9		15	1	9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	1
Time:	33		39		36		29		38		27		31		37		39	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	16	R = 23	23	R = 17	14	W= 18	18	W= 19	19	W= 20	20
Time:	43		46		49		36		39		41		34		42		41	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4	1	9		23		27		10		1	
20	5		16		5		12		28		7		11	1	26		7	
21	7		3		20	1	26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13	1	28		8		3		14		13		14	
24	8		14		31		1		26		9		30	1	21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1	1	19		19		28		20	
31	30		32		12		8		20		32		3	1	17		25	
32	1		26		8		31		3		11		12	1	1		30	
Time:	29		37		39		30		39		33		43		30		38	
Errors:	0		1		3		1		1		0		4		2		2	

Subject no:8 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5	1	9		17		23		30		24		19		23	1
3	4		30		14		20	1	27		8		9		3	1	17	
4	14		10	1	23		7		6	1	1		23		31		2	
5	17		19		17	1	30		10		16		18		20	1	28	
6	21		28		28		5		29		12		6		4		18	
7	29		12	1	24		29	1	15		24		29		22	1	6	
8	12		21		10	1	6		18		14		2		16		24	1
9	15		15		22		18		21	1	26		28		5		29	1
10	10	1	31	1	7	1	16		12		5		21		14		9	1
11	24		9		15		9		25		13		13		30		13	
12	6		13		19	1	32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10	1	27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	38		47		40		39		39		39		43		41		47	
Letter count:	N = 18	12	N = 16	9	N = 19	17	R = 17	13	R = 23	20	R = 17	13	W= 18	17	W= 19	17	W= 20	18
Time:	36		32		44		37		41		37		33		41		38	
17	20		18		11	1	27		22		18		15		15		31	
18	16		29	1	2		10	1	14		10		8	1	32		26	
19	23	1	22		18	1	4		9	1	23		27		10	1	1	1
20	5		16	1	5	1	12		28		7		11		26		7	
21	7	1	3		20	1	26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14	1	31	1	1		26		9		30	1	21		5	1
25	28		11		21		13		13		20	1	22		2		22	
26	11		24		25		24		4		27		16		9	1	16	
27	27		8		6		2		24		6		4		29		4	
28	13	1	17		27		19		16		31		20	1	6	1	27	1
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23		1		19	1	19		28		20	
31	30		32		12	1	8		20		32	1	3		17		25	
32	1	1	26		8		31		3		11	1	12	1	1		30	
Time:	44		36		50		36		37		46		54		49		48	
Errors:	5		7		10		3		3		4		5		7		8	

Subject no:9 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5	1	9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28	1	28		5		29		12		6		4		18	
7	29		12		24		29	1	15		24		29		22		6	1
8	12		21		10	1	6		18		14		2		16	1	24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7	1	16		12		5	1	21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6	1	13		19		32		2		21	1	5		12		8	
13	26		6		3		3		30		28	1	17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31	1	2		10		27	1	3	
16	25		20		29		21		11		15		26		8		15	
Time:	26		33		29		33		29		39		24		40		32	
Letter count:	N = 18	16	N = 16	14	N = 19	18	R = 17	9	R = 23	21	R = 17	11	W= 18	17	W= 19	15	W= 20	19
Time:	36		34		45		30		28		31		25		26		25	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8	1	32		26	
19	23		22		18		4		9		23		27		10		1	
20	5	1	16		5	1	12		28		7		11		26		7	
21	7		3		20		26	1	19		29		31		23		19	1
22	22		27		4	1	15		5		17	1	7		18		12	
23	31		2	1	13		28		8		3		14		13		14	
24	8		14		31	1	1		26		9		30		21		5	
25	28	1	11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	1
27	27		8		6	1	2		24	1	6		4	1	29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4	1	25		24		10	1
30	32		4	1	1		23		1		19		19		28	1	20	
31	30		32		12		8		20		32		3		17		25	
32	1		26	1	8		31		3		11		12		1		30	
Time:	36		33		39		29		36		33		36		40		38	
Errors:	3		5		6		2		2		5		2		3		5	

Subject no:10 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3	1	17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	1
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5	1	29	
10	10		31		7		16		12		5		21		14	1	9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	1
14	18		1		26		14	1	7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	42		32		34		35		29		34		42		50		38	
Letter count:	N = 18	18	N = 16	16	N = 19	18	R = 17	13	R = 23	22	R = 17	12	W= 18	17	W= 19	19	W= 20	20
Time:	49		40		50		38		39		36		39		44		47	
17	20		18		11		27		22		18		15		15		31	1
18	16		29		2		10		14		10		8		32		26	
19	23		22	1	18	1	4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20	1	26		19		29		31		23		19	
22	22		27		4	1	15		5		17		7		18	1	12	1
23	31		2		13		28		8		3	1	14		13		14	
24	8		14		31		1		26		9		30		21	1	5	
25	28		11		21		13		13		20		22		2		22	1
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	
30	32		4	1	1		23		1		19		19		28		20	
31	30		32		12		8		20		32		3	1	17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	37		44		44		37		37		40		44		42		44	
Errors:	0		2		3		1		0		1		1		6		6	

Subject no:11 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9	1	17		23		30	1	24		19	1	23	
3	4		30		14		20	1	27		8		9		3		17	
4	14		10	1	23		7		6		1		23		31		2	
5	17		19		17	1	30		10		16		18	1	20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24	1	29		15		24		29		22		6	
8	12	1	21		10	1	6		18		14		2		16		24	
9	15		15		22		18		21		26	1	28		5		29	1
10	10	1	31		7		16		12	1	5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13	1	19		32		2		21		5		12		8	
13	26		6	1	3		3	1	30		28		17		7		32	
14	18		1		26	1	14		7		22		32		11		21	1
15	9		25		32	1	11		31		2		10		27		3	1
16	25		20		29		21	1	11		15		26	1	8		15	
Time:	50		63		62		50		65		66		59		60		67	
Letter count:	N = 18	17	N = 16	15	N = 19	17	R = 17	14	R = 23	22	R = 17	12	W= 18	18	W= 19	19	W= 20	20
Time:	39		35		43		35		41		36		31		41		48	
17	20		18		11		27		22		18		15		15		31	1
18	16		29		2	1	10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	1
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31	1	1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	1
26	11		24		25	1	24		4		27		16		9		16	
27	27	1	8		6		2		24		6		4	1	29		4	1
28	13		17		27	1	19		16		31		20	1	6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23	1	1		19		19	1	28		20	
31	30	1	32		12		8		20		32		3		17		25	
32	1		26	1	8		31		3		11		12		1		30	
Time:	66		64		51		62		67		63		55		65		63	
Errors:	4		4		10		4		1		2		5		1		8	

Subject no:12 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30	1	22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14	1	20		27		8		9		3		17	
4	14		10	1	23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5	1	29		12		6		4		18	1
7	29		12		24		29		15		24		29		22		6	
8	12		21		10	1	6	1	18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10	1	31		7		16		12		5		21		14		9	
11	24		9		15		9		25	1	13		13		30		13	1
12	6		13		19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7	1	32	
14	18		1		26		14	1	7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	41		48		65		35		49		44		34		45		63	
Letter count:	N = 18	15	N = 16	9	N = 19	12	R = 17	12	R = 23	18	R = 17	16	W= 18	16	W= 19	18	W= 20	18
Time:	47		42		55		45		47		53		41		45		47	
17	20	1	18		11	1	27		22		18	1	15		15		31	1
18	16		29		2		10	1	14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7	1	11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27	1	4		15		5		17		7		18		12	1
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	1
25	28		11	1	21		13		13		20		22		2		22	
26	11		24		25		24	1	4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4	1	25		24		10	
30	32		4		1		23		1	1	19	1	19		28		20	
31	30		32		12	1	8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1	1	30	1
Time:	49		56		66		44		48		48		39		45		53	
Errors:	2		3		5		5		2		4		0		2		6	

Subject no:13 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6	1	1		23		31		2	
5	17		19	1	17		30		10		16		18		20		28	1
6	21		28		28		5		29	1	12		6		4		18	1
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28	1	5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	1
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26	1	8	1	15	1
Time:	29		41		37		31		32		30		30		35		45	
Letter count:	N = 18	16	N = 16	15	N = 19	16	R = 17	17	R = 23	19	R = 17	13	W= 18	17	W= 19	17	W= 20	20
Time:	34		34		37		39		43		37		30		40		42	
17	20		18		11		27		22	1	18		15		15		31	
18	16		29	1	2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5	1	16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24	1	25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23	1	16		25		32		4		25		24		10	1
30	32		4		1		23		1		19		19		28		20	
31	30		32	1	12		8		20		32	1	3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	41		41		31		30		30		38		33		40		43	
Errors:	1		5		0		0		3		1		2		1		7	

Subject no:14 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7	1	30		22		17		25		1		25		11	
2	3		5		9		17		23		30	1	24		19	1	23	
3	4		30	1	14	1	20		27		8		9		3		17	1
4	14		10	1	23		7		6		1		23		31	1	2	1
5	17		19		17		30	1	10		16	1	18		20		28	
6	21		28		28		5		29	1	12		6		4		18	
7	29		12		24		29	1	15		24		29	1	22		6	
8	12	1	21	1	10		6		18		14		2		16		24	
9	15		15	1	22		18		21	1	26		28	1	5		29	
10	10		31		7	1	16		12		5		21	1	14		9	1
11	24		9		15	1	9		25		13		13		30		13	
12	6		13	1	19		32		2		21	1	5		12		8	
13	26		6		3	1	3	1	30	1	28		17	1	7		32	
14	18		1		26		14		7	1	22		32		11	1	21	
15	9		25		32		11		31		2		10		27		3	1
16	25		20		29	1	21		11		15		26		8	1	15	
Time:	45		49		45		40		45		54		43		46		45	
Letter count:	N = 18	17	N = 16	11	N = 19	18	R = 17	15	R = 23	18	R = 17	12	W= 18	17	W= 19	18	W= 20	18
Time:	48		45		56		45		51		54		37		55		50	
17	20		18		11	1	27		22		18		15	1	15	1	31	1
18	16		29	1	2		10		14		10		8		32		26	
19	23		22		18		4	1	9	1	23		27		10		1	1
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26	1	19		29		31		23		19	
22	22		27		4		15		5	1	17	1	7		18		12	1
23	31	1	2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20	1	22	1	2		22	
26	11		24		25		24		4		27		16		9	1	16	
27	27	1	8	1	6		2		24		6		4	1	29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4	1	25	1	24	1	10	1
30	32	11	4		1	1	23		1		19	1	19		28		20	
31	30		32	1	12		8		20	1	32		3		17		25	
32	1		26		8	1	31		3		11		12		1	1	30	1
Time:	42		51		49		40		48		50		45		49		49	
Errors:	14		9		8		5		7		7		8		8		9	

Subject no:15 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30	1	22		17		25		1		25		11	1
2	3		5		9		17		23		30		24		19		23	
3	4		30		14	1	20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28	1	28	1	5		29		12		6		4	1	18	1
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15	1	22		18		21		26		28		5		29	
10	10	1	31		7		16		12		5		21		14		9	
11	24		9		15		9		25	1	13		13		30		13	1
12	6		13	1	19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14	1	7		22		32		11	1	21	
15	9		25		32		11		31		2		10		27		3	
16	25		20	1	29		21		11	1	15		26		8		15	
Time:	45		50		43		39		36		45		40		50		57	
Letter count:	N = 18	16	N = 16	14	N = 19	18	R = 17	17	R = 23	23	R = 17	16	W= 18	18	W= 19	19	W= 20	20
Time:	70		65		83		69		64		66		60		68		73	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2	1	10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16	1	5		12		28	1	7		11	1	26		7	
21	7		3		20		26		19		29		31		23	1	19	
22	22		27		4		15		5		17		7		18		12	1
23	31		2	1	13		28		8		3		14		13		14	
24	8		14		31	1	1		26		9		30		21		5	
25	28		11		21	1	13		13		20		22		2	1	22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32	1	4		25		24		10	1
30	32	1	4		1	1	23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	1
Time:	40		58		51		43		45		44		50		47		54	
Errors:	2		6		7		1		4		0		1		4		6	

Subject no:16 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9	1	3	1	17	
4	14		10		23		7		6		1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12	1	6	1	4	1	18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	1
12	6		13		19		32		2		21		5		12	1	8	
13	26	1	6		3		3		30		28		17		7		32	
14	18		1		26		14		7	1	22		32		11		21	
15	9		25		32		11		31		2		10		27	1	3	1
16	25		20		29		21		11		15		26		8		15	
Time:	38		63		39		38		37		44		40		45		46	
Letter count:	N = 18	18	N = 16	14	N = 19	19	R = 17	16	R = 23	20	R = 17	16	W= 18	17	W= 19	15	W= 20	20
Time:	56		61		56		52		54		54		40		43		44	
17	20		18	1	11	1	27		22		18		15		15		31	
18	16	1	29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10	1	1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18	1	12	1
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6	1	4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19		19		28		20	
31	30	1	32		12		8		20	1	32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	41		66		49		41		44		42		39		47		48	
Errors:	3		1		1		0		2		2		2		6		4	

Subject no:17 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24	1	19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6	1	1		23		31	1	2	
5	17		19		17		30		10		16		18	1	20	1	28	1
6	21		28		28	1	5		29		12		6		4		18	1
7	29		12		24		29		15		24	1	29		22	1	6	1
8	12		21		10		6		18		14		2		16	1	24	
9	15		15	1	22		18		21		26		28		5	1	29	
10	10		31		7		16		12	1	5		21	1	14	1	9	
11	24		9		15		9		25		13		13		30	1	13	
12	6		13		19		32		2		21		5		12	1	8	1
13	26		6		3		3		30		28		17		7	1	32	
14	18		1	1	26		14	1	7		22		32		11	1	21	
15	9	1	25	1	32		11		31	1	2	1	10		27	1	3	
16	25		20		29	1	21		11	1	15		26		8	1	15	
Time:	30		48		34		40		43		34		48		64		50	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	17	R = 23	19	R = 17	13	W= 18	18	W= 19	18	W= 20	20
Time:	50		46		59		50		47		50		42		47		61	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14	1	10	1	8		32		26	1
19	23		22		18	1	4		9		23		27		10		1	
20	5		16	1	5		12		28		7		11		26		7	
21	7		3	1	20		26		19		29		31		23	1	19	
22	22		27	1	4		15		5		17		7		18		12	1
23	31		2		13		28		8		3		14		13	1	14	
24	8		14		31		1		26		9	1	30		21		5	
25	28		11	1	21		13		13		20		22		2		22	
26	11		24		25		24		4		27	1	16		9		16	1
27	27		8	1	6		2		24		6		4	1	29	1	4	1
28	13		17	1	27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	1
30	32	1	4		1	1	23		1		19		19		28	1	20	
31	30	1	32	1	12		8		20	1	32		3		17		25	
32	1		26	1	8	1	31		3		11		12	1	1		30	
Time:	50		54		46		42		48		40		51		54		54	
Errors:	3		11		5		1		6		5		5		16		11	

Subject no:18 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30	1	10		16		18		20		28	1
6	21		28		28		5	1	29		12		6		4		18	
7	29		12		24		29	1	15		24		29		22	1	6	
8	12		21		10	1	6		18		14	1	2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7	1	16		12		5	1	21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6	1	13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28	1	17	1	7		32	1
14	18		1		26		14	1	7		22		32		11	1	21	
15	9		25		32		11		31		2	1	10		27		3	
16	25	1	20		29	1	21		11		15		26		8		15	
Time:	35		34		41		46		34		45		35		40		50	
Letter count:	N = 18	18	N = 16	16	N = 19	17	R = 17	15	R = 23	21	R = 17	13	W= 18	15	W= 19	19	W= 20	20
Time:	35		31		38		49		31		40		22		24		30	
17	20		18		11	1	27		22		18		15		15		31	
18	16		29		2	1	10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12	1	28		7		11		26	1	7	1
21	7		3		20		26	1	19		29		31		23		19	
22	22		27		4		15	1	5		17		7	1	18		12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21	1	5	1
25	28		11		21		13		13		20		22		2	1	22	1
26	11		24		25		24		4		27		16		9		16	1
27	27		8		6		2		24		6	1	4		29	1	4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24	1	10	
30	32		4		1		23		1		19		19		28		20	1
31	30	1	32		12		8		20	1	32		3		17		25	
32	1		26		8	1	31		3		11	1	12		1		30	1
Time:	35		33		46		43		40		42		46		40		50	
Errors:	3		0		6		7		1		6		2		8		10	

Subject no:19 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17	1	23		30	1	24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19	1	17	1	30		10		16		18		20		28	1
6	21		28		28		5		29		12	1	6		4		18	1
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28	1	5		29	
10	10		31		7		16		12		5		21		14	1	9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	
13	26		6		3		3		30	1	28		17		7		32	
14	18		1		26		14	1	7		22		32		11	1	21	
15	9		25		32		11		31	1	2		10		27		3	1
16	25		20		29		21		11		15		26		8		15	
Time:	33		36		38		40		35		40		39		40		42	
Letter count:	N = 18	17	N = 16	16	N = 19	19	R = 17	16	R = 23	22	R = 17	16	W= 18	18	W= 19	19	W= 20	20
Time:	54		48		61		65		58		77		57		80		54	
17	20		18		11		27		22		18		15		15		31	1
18	16	1	29		2		10	1	14	1	10		8		32	1	26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26	1	7	
21	7		3		20		26		19		29		31		23		19	1
22	22		27		4	1	15		5		17	1	7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2	1	22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6	1	4	1	29		4	1
28	13		17		27		19		16		31	1	20		6		27	
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23		1		19	1	19		28		20	
31	30	1	32		12		8		20	1	32	1	3	1	17		25	
32	1		26		8		31		3	1	11		12		1		30	
Time:	33		37		41		30		45		47		44		42		44	
Errors:	2		1		2		3		5		7		3		5		7	

Subject no:20 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8	1	9		3		17	
4	14		10		23		7		6		1		23		31	1	2	
5	17		19		17		30		10		16	1	18		20		28	1
6	21	1	28		28		5		29	1	12	1	6		4		18	
7	29		12		24		29		15		24	1	29		22		6	
8	12		21		10		6		18	1	14		2		16		24	
9	15		15		22		18		21		26		28		5	1	29	1
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2	1	21		5	1	12		8	
13	26		6		3	1	3		30		28		17		7	1	32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27	1	3	
16	25		20		29		21		11	1	15		26		8	1	15	
Time:	31		36		39		45		46		45		36		47		50	
Letter count:	N = 18	16	N = 16	16	N = 19	19	R = 17	16	R = 23	22	R = 17	16	W= 18	18	W= 19	18	W= 20	20
Time:	64		58		42		61		59		60		61		76		75	
17	20		18		11		27		22		18	1	15		15	1	31	
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23	1	27		10		1	1
20	5		16		5		12		28		7	1	11		26		7	
21	7		3		20	1	26		19		29		31		23		19	1
22	22		27		4		15		5		17		7		18		12	1
23	31		2		13	1	28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24	1	4		27		16		9		16	
27	27	1	8		6		2		24		6	1	4		29		4	1
28	13		17		27		19		16	1	31		20		6	1	27	1
29	2		23		16		25		32		4		25		24		10	
30	32		4		1	1	23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	33		37		53		41		48		47		44		43		45	
Errors:	2		0		4		1		5		8		1		7		8	

Subject no:21 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19	1	23	
3	4		30		14		20	1	27	1	8		9		3		17	
4	14		10		23		7		6		1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12	1	6		4		18	1
7	29		12		24	1	29		15		24		29		22		6	1
8	12		21		10		6		18		14	1	2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12	1	5		21		14		9	1
11	24		9		15		9		25		13	1	13		30		13	
12	6		13	1	19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7		32	1
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32	1	11		31		2		10		27		3	1
16	25		20		29	1	21		11		15		26		8	1	15	1
Time:	32		33		39		34		42		46		35		45		50	
Letter count:	N = 18	15	N = 16	14	N = 19	15	R = 17	15	R = 23	20	R = 17	12	W= 18	15	W= 19	20	W= 20	19
Time:	77		63		91		66		84		84		55		74		85	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14	1	10		8		32		26	
19	23		22	1	18		4		9		23		27		10	1	1	1
20	5		16		5		12		28		7		11		26	1	7	
21	7		3		20		26	1	19	1	29		31		23		19	
22	22		27		4		15		5		17		7		18	1	12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31	1	1		26		9		30		21	1	5	
25	28		11	1	21		13		13	1	20		22		2		22	1
26	11		24		25	1	24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	
30	32		4		1	1	23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17		25	
32	1	1	26		8		31		3		11	1	12		1		30	
Time:	39		44		45		34		40		39		36		42		45	
Errors:	1		3		6		2		5		4		0		7		12	

Subject no:22 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14	1	20		27	1	8		9		3		17	1
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30	1	10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	1
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30	1	13	
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	30		31		37		33		40		32		31		39		45	
Letter count:	N = 18	18	N = 16	12	N = 19	19	R = 17	15	R = 23	21	R = 17	13	W= 18	17	W= 19	19	W= 20	22
Time:	75		64		26		62		64		65		53		55		53	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8	1	32		26	1
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	1
21	7		3		20		26	1	19		29		31		23		19	
22	22		27		4		15		5		17		7		18	1	12	1
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	1
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4	1	29		4	
28	13		17		27	1	19		16		31	1	20	1	6		27	
29	2		23		16		25		32		4		25		24	1	10	
30	32		4		1		23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	1
32	1		26		8		31		3		11		12		1		30	1
Time:	28		33		39		34		40		35		42		39		52	
Errors:	0		0		2		2		1		1		3		5		8	

Subject no:23 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24	1	19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	1
5	17		19		17		30		10		16		18		20	1	28	
6	21		28		28		5		29		12		6		4	1	18	
7	29		12		24		29		15		24	1	29		22	1	6	1
8	12		21		10		6		18		14		2		16	1	24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16	1	12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22	1	32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29	1	21	1	11		15		26		8		15	
Time:	30		28		31		34		39		39		39		40		44	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	17	R = 23	23	R = 17	16	W= 18	17	W= 19	19	W= 20	22
Time:	46		47		56		46		51		46		45		51		48	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27	1	10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23	1	19	1
22	22		27		4		15		5		17		7		18	1	12	
23	31		2		13		28		8	1	3		14		13		14	
24	8		14		31		1		26		9		30		21		5	1
25	28		11	1	21		13		13		20		22	1	2	1	22	1
26	11		24		25		24		4		27		16		9		16	
27	27		8	1	6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6	1	27	
29	2		23		16		25		32		4		25	1	24		10	1
30	32		4		1		23		1		19		19		28	1	20	1
31	30		32		12		8		20		32		3		17		25	1
32	1		26		8		31		3		11		12		1	1	30	
Time:	35		38		27		32		38		32		40		44		43	
Errors:	0		2		1		2		1		2		4		10		9	

Subject no:24 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9	1	17		23	1	30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6	1	1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6	1	4	1	18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5	1	29	1
10	10		31		7		16		12	1	5		21		14		9	
11	24	1	9		15		9		25	1	13		13		30	1	13	
12	6		13		19		32		2		21		5		12	1	8	1
13	26		6		3	1	3		30		28		17		7	1	32	1
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	1
16	25		20		29		21		11		15		26		8	1	15	
Time:	64		63		67		64		65		66		65		65		66	
Letter count:	N = 18	15	N = 16	14	N = 19	16	R = 17	17	R = 23	22	R = 17	14	W= 18	16	W= 19	19	W= 20	19
Time:	41		42		41		46		57		54		35		50		44	
17	20		18		11		27		22		18		15		15		31	1
18	16		29	1	2	1	10		14		10		8		32		26	
19	23		22		18	1	4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23	1	19	
22	22		27		4		15		5		17		7		18		12	1
23	31		2		13		28		8		3		14		13		14	
24	8		14		31	1	1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2	1	22	
26	11		24		25		24		4		27		16		9	1	16	
27	27		8		6		2		24		6	1	4		29		4	1
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	1
30	32		4	1	1	1	23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17		25	
32	1	1	26		8		31		3	1	11	1	12		1		30	
Time:	74		64		65		75		68		71		70		66		64	
Errors:	2		2		6		0		5		2		1		9		12	

Subject no:25 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30	1	24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10	1	23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	1
6	21		28		28	1	5		29		12		6		4		18	1
7	29		12		24		29	1	15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	1
9	15		15		22		18		21	1	26		28		5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15	1	9		25		13		13		30		13	1
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3	1	3	1	30		28		17		7		32	1
14	18		1		26	1	14		7		22	1	32		11	1	21	
15	9		25		32	1	11	1	31	1	2		10	1	27		3	
16	25		20		29		21		11	1	15		26		8		15	
Time:	63		63		64		65		68		64		65		64		66	
Letter count:	N = 18	18	N = 16	11	N = 19	14	R = 17	14	R = 23	20	R = 17	11	W= 18	15	W= 19	18	W= 20	16
Time:	62		52		56		40		47		49		43		54		43	
17	20		18		11	1	27		22		18		15		15		31	
18	16		29		2		10	1	14		10	1	8		32		26	
19	23		22		18		4		9		23		27		10	1	1	
20	5		16		5		12		28		7		11		26	1	7	
21	7		3		20		26		19		29	1	31		23		19	1
22	22		27		4		15		5		17		7		18		12	1
23	31		2		13	1	28		8		3	1	14		13		14	
24	8		14		31		1		26		9	1	30	1	21		5	
25	28		11	1	21	1	13		13		20		22	1	2		22	1
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	1
28	13		17		27		19		16		31		20		6		27	
29	2		23		16	1	25		32		4		25		24		10	1
30	32		4		1		23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17	1	25	1
32	1		26		8		31		3		11	1	12		1		30	
Time:	69		67		70		68		67		71		66		66		71	
Errors:	0		2		9		4		3		7		3		4		14	

Subject no:26 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12	1	24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2	1	16		24	
9	15		15		22		18		21		26		28	1	5		29	1
10	10	1	31		7		16		12		5		21		14		9	1
11	24		9		15		9	1	25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3	1	3		30		28		17	1	7		32	1
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	47		49		46		55		40		44		46		48		54	
Letter count:	N = 18	18	N = 16	16	N = 19	17	R = 17	17	R = 23	21	R = 17	13	W= 18	17	W= 19	19	W= 20	20
Time:	51		51		62		45		50		61		49		53		63	
17	20		18		11		27		22		18	1	15		15		31	
18	16		29		2		10		14		10	1	8		32		26	
19	23		22		18		4		9		23		27		10	1	1	
20	5		16		5		12		28		7	1	11		26		7	
21	7		3		20		26		19	1	29		31		23	1	19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27	1	16		9		16	
27	27		8		6		2		24		6		4	1	29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24	1	10	1
30	32		4		1	1	23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11	1	12		1		30	
Time:	47		43		50		48		49		50		44		55		59	
Errors:	1		1		2		1		1		5		4		3		7	

Subject no:27 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30	1	24		19		23	
3	4		30	1	14		20	1	27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	1
5	17		19		17	1	30		10		16	1	18		20		28	
6	21	1	28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22	1	6	
8	12		21		10		6		18		14		2		16		24	1
9	15		15		22	1	18		21		26		28		5		29	
10	10		31		7	1	16		12		5		21		14		9	1
11	24		9		15	1	9		25		13		13		30	1	13	
12	6		13		19	1	32		2		21		5		12	1	8	
13	26		6		3	1	3		30		28		17		7		32	1
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	38		39		48		40		38		54		40		44		47	
Letter count:	N = 18	16	N = 16	14	N = 19	19	R = 17	16	R = 23	23	R = 17	16	W= 18	17	W= 19	17	W= 20	20
Time:	67		61		82		73		63		70		40		47		50	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2	1	10		14	1	10	1	8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26	1	19		29		31		23		19	
22	22		27		4		15		5		17		7		18	1	12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22	1	2	1	22	
26	11	1	24		25	1	24		4		27	1	16		9	1	16	
27	27		8		6		2		24		6		4		29	1	4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1	1	19		19		28	1	20	1
31	30		32		12		8		20		32		3		17		25	1
32	1		26		8		31	1	3		11		12		1		30	1
Time:	39		40		50		40		40		41		49		48		51	
Errors:	2		1		8		3		2		4		1		8		7	

Subject no:28 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5	1	9		17		23		30	1	24		19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2	1	16		24	1
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3		3		30		28		17		7		32	1
14	18		1	1	26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	38		44		39		39		32		44		46		50		60	
Letter count:	N = 18	18	N = 16	15	N = 19	19	R = 17	14	R = 23	20	R = 17	16	W= 18	17	W= 19	19	W= 20	20
Time:	53		46		61		51		50		46		42		45		54	
17	20		18		11	1	27		22		18		15		15		31	1
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20	1	26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13	1	28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2	1	22	
26	11		24		25		24		4		27		16		9		16	1
27	27		8		6		2		24		6		4		29		4	1
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32	1	4		25		24		10	1
30	32		4		1		23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8	1	31		3		11		12		1		30	
Time:	38		44		48		38		47		42		42		49		50	
Errors:	0		2		4		0		1		1		1		1		10	

Subject no:29 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22	1	17		25		1		25		11	1
2	3	1	5	1	9	1	17		23	1	30		24		19	1	23	
3	4		30	1	14		20		27	1	8	1	9	1	3	1	17	
4	14		10		23		7	1	6	1	1		23	1	31		2	1
5	17		19		17		30		10	1	16		18		20		28	
6	21		28		28		5		29	1	12		6		4	1	18	1
7	29	1	12		24		29		15		24		29	1	22		6	
8	12	1	21	1	10		6		18	1	14		2	1	16	1	24	
9	15		15		22		18		21		26		28	1	5	1	29	1
10	10		31		7		16	1	12	1	5		21	1	14	1	9	1
11	24		9		15		9	1	25		13		13		30	1	13	
12	6		13	1	19		32		2	1	21		5	1	12	1	8	1
13	26		6	1	3	1	3	1	30	1	28		17		7		32	1
14	18		1	1	26	1	14		7		22		32		11		21	
15	9		25		32	1	11	1	31	1	2		10		27		3	1
16	25	1	20	1	29		21	1	11	1	15		26		8	1	15	1
Time:	68		67		64		68		67		64		65		66		67	
Letter count:	N = 18	14	N = 16	8	N = 19	15	R = 17	14	R = 23	17	R = 17	12	W= 18	15	W= 19	16	W= 20	14
Time:	37		38		49		35		44		42		33		35		37	
17	20		18		11		27	1	22	1	18		15		15		31	1
18	16		29	1	2	1	10		14		10	1	8	1	32	1	26	
19	23		22	1	18		4		9	1	23		27		10	1	1	
20	5		16		5		12		28		7	1	11		26		7	1
21	7	1	3		20	1	26		19		29		31		23	1	19	
22	22		27		4		15		5	1	17	1	7		18		12	1
23	31	1	2		13		28		8	1	3		14	1	13	1	14	
24	8	1	14		31		1		26	1	9	1	30	1	21		5	1
25	28		11	1	21	1	13		13	1	20	1	22	1	2		22	
26	11	1	24		25	1	24		4	1	27		16		9	1	16	1
27	27		8	1	6	1	2		24	1	6	1	4		29	1	4	1
28	13		17	1	27		19		16	1	31	1	20	1	6	1	27	
29	2		23	1	16		25		32		4	1	25	1	24		10	
30	32	1	4		1		23	1	1	1	19		19	1	28	1	20	1
31	30	1	32	1	12	1	8		20		32		3	1	17	1	25	1
32	1	1	26	1	8		31		3		11		12	1	1	1	30	1
Time:	70		70		66		67		67		69		67		68		66	
Errors:	11		15		10		9		21		9		16		19		18	

Subject no:30 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17	1	23		30		24		19	1	23	
3	4		30		14		20		27		8		9		3	1	17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6	1	4		18	
7	29		12		24		29		15		24	1	29		22		6	1
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21	1	26	1	28		5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2	1	21		5		12		8	
13	26		6		3		3		30		28		17	1	7		32	
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32		11		31		2		10		27		3	1
16	25		20		29	1	21		11		15		26		8		15	1
Time:	40		45		39		40		52		40		45		45		54	
Letter count:	N = 18	17	N = 16	15	N = 19	17	R = 17	14	R = 23	22	R = 17	15	W= 18	17	W= 19	19	W= 20	19
Time:	45		40		47		41		48		47		35		40		37	
17	20		18		11		27		22		18		15		15	1	31	1
18	16		29		2	1	10		14		10		8		32		26	1
19	23		22		18	1	4		9	1	23		27		10	1	1	
20	5		16		5		12		28		7		11		26		7	
21	7	1	3		20		26		19		29		31	1	23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	1
25	28		11	1	21		13		13		20		22		2	1	22	
26	11		24		25		24		4		27		16		9		16	
27	27	1	8		6		2	1	24		6		4		29		4	1
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4	1	25		24		10	
30	32		4		1		23	1	1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	45		48		48		40		41		40		48		59		33	
Errors:	2		1		3		3		3		3		3		6		8	

Subject no:31 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23	1	30		24		19		23	
3	4		30		14		20		27	1	8	1	9		3		17	1
4	14		10		23		7		6		1		23		31		2	
5	17	1	19		17		30	1	10		16	1	18	1	20		28	1
6	21		28		28	1	5		29		12	1	6		4		18	
7	29		12		24		29	1	15		24		29		22		6	
8	12		21		10		6		18		14		2	1	16		24	
9	15		15		22		18		21		26		28		5		29	
10	10	1	31		7		16		12	1	5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19	1	32		2	1	21	1	5	1	12		8	1
13	26		6		3		3	1	30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25	1	32		11	1	31		2		10		27		3	1
16	25		20		29		21		11	1	15		26		8		15	
Time:	41		44		38		43		42		44		40		43		44	
Letter count:	N = 18	18	N = 16	16	N = 19	18	R = 17	16	R = 23	23	R = 17	17	W= 18	18	W= 19	19	W= 20	20
Time:	81		73		82		81		86		84		62		88		84	
17	20		18		11		27	1	22		18		15		15		31	1
18	16		29		2		10		14	1	10		8		32		26	
19	23		22		18		4	1	9		23		27	1	10		1	1
20	5		16		5		12		28		7		11		26		7	1
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8	1	3		14		13		14	1
24	8		14	1	31		1		26		9	1	30		21		5	
25	28		11		21		13		13		20	1	22		2		22	1
26	11		24		25		24		4		27	1	16		9	1	16	
27	27		8		6	1	2		24		6		4	1	29		4	1
28	13		17		27		19		16		31	1	20		6	1	27	
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23		1		19		19		28	1	20	
31	30		32		12	1	8		20		32		3		17		25	1
32	1		26		8		31		3		11	1	12		1		30	1
Time:	48		46		47		55		40		49		47		56		56	
Errors:	2		2		4		6		7		9		5		3		13	

Subject no:32 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23	1	30		24		19		23	
3	4		30	1	14		20		27		8		9		3		17	
4	14		10		23		7		6	1	1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12	1	6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2	1	16		24	
9	15		15		22		18		21		26	1	28		5		29	1
10	10		31		7		16		12	1	5		21		14	1	9	
11	24		9		15		9		25		13		13	1	30	1	13	
12	6	1	13		19		32		2	1	21		5		12		8	1
13	26		6		3		3		30		28	1	17		7		32	
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32		11		31		2	1	10		27		3	
16	25		20		29		21	1	11	1	15		26		8		15	
Time:	40		43		41		35		50		49		42		48		44	
Letter count:	N = 18	15	N = 16	14	N = 19	17	R = 17	14	R = 23	18	R = 17	10	W= 18	18	W= 19	14	W= 20	17
Time:	39		42		39		40		40		37		33		41		38	
17	20		18	1	11		27		22		18		15		15		31	
18	16		29		2		10		14		10	1	8	1	32		26	1
19	23		22		18	1	4		9		23		27		10		1	
20	5		16		5		12	1	28		7		11		26		7	1
21	7		3		20		26		19	1	29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2	1	13		28		8		3		14		13		14	1
24	8	1	14		31		1		26		9		30		21		5	
25	28		11		21	1	13		13		20		22		2		22	
26	11	1	24		25		24		4		27		16	1	9	1	16	1
27	27		8		6		2		24		6		4	1	29		4	1
28	13	1	17		27		19		16		31	1	20	1	6		27	1
29	2		23		16		25		32	1	4	1	25		24		10	1
30	32	1	4		1		23		1		19		19		28		20	
31	30		32		12	1	8		20		32	1	3		17		25	1
32	1		26		8		31		3		11		12	1	1		30	
Time:	41		44		46		38		40		46		40		47		60	
Errors:	5		3		3		2		7		8		7		4		11	

Subject no:33 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14	1	20		27		8		9	1	3	1	17	1
4	14		10		23		7		6		1		23		31		2	
5	17		19		17	1	30		10		16	1	18		20	1	28	
6	21		28		28		5	1	29		12	1	6	1	4		18	1
7	29		12		24		29		15		24		29		22		6	
8	12		21		10	1	6		18		14		2		16		24	1
9	15		15		22		18		21		26		28		5	1	29	1
10	10		31		7	1	16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19	1	32		2		21		5		12	1	8	
13	26		6		3		3		30		28	1	17		7		32	
14	18		1		26		14	1	7		22		32		11	1	21	1
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	45		51		45		40		40		40		47		46		50	
Letter count:	N = 18	17	N = 16	16	N = 19	18	R = 17	16	R = 23	23	R = 17	15	W= 18	18	W= 19	17	W= 20	18
Time:	54		80		54		52		53		53		58		58		74	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10	1	8	1	32		26	1
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22	1	27		4		15		5	1	17		7		18		12	1
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21	1	5	1
25	28		11		21		13		13		20		22		2		22	1
26	11		24		25		24		4		27		16		9		16	1
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16	1	25		32		4		25	1	24		10	
30	32		4		1		23		1		19		19	1	28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1	1	30	
Time:	51		53		48		43		50		43		51		59		54	
Errors:	1		0		6		2		1		4		5		7		10	

Subject no:34 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	1
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28	1	5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	1
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7	1	22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	32		33		44		34		30		38		41		50		53	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	16	R = 23	23	R = 17	17	W= 18	18	W= 19	19	W= 20	20
Time:	43		43		59		55		47		52		66		55		46	
17	20		18		11		27		22		18		15		15		31	1
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12	1	1	1	30	
Time:	36		42		40		33		43		37		43		49		52	
Errors:	0		0		0		0		1		0		2		1		4	

Subject no:35 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7	1	6		1		23		31		2	
5	17		19		17		30		10		16	1	18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10	1	6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25		13		13	1	30		13	1
12	6		13		19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7	1	22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26	1	8		15	
Time:	42		36		64		39		43		35		52		64		64	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	16	R = 23	18	R = 17	13	W= 18	18	W= 19	18	W= 20	17
Time:	47		40		50		32		37		41		44		71		52	
17	20		18		11	1	27		22		18		15	1	15		31	
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	1
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9	1	16	
27	27		8		6		2	1	24		6		4		29		4	
28	13		17		27		19		16		31		20		6	1	27	1
29	2		23		16		25	1	32		4		25		24		10	
30	32		4		1		23	1	1		19		19		28	1	20	1
31	30	1	32	1	12		8		20		32	1	3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	42		39		65		41		50		45		64		65		64	
Errors:	1		1		2		4		1		2		3		3		6	

Subject no:36 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19	1	23	
3	4		30		14		20	1	27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29	1	12		24		29		15		24		29	1	22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30	1	13	
12	6		13		19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10	1	27		3	
16	25		20		29		21		11		15		26		8	1	15	
Time:	32		33		32		32		35		27		41		46		44	
Letter count:	N = 18	18	N = 16	16	N = 19	18	R = 17	16	R = 23	21	R = 17	16	W= 18	17	W= 19	19	W= 20	19
Time:	63		60		77		58		61		68		68		57		68	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8		32		26	1
19	23		22		18	1	4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19	1	29		31		23		19	1
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8	1	3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23		1		19		19		28		20	1
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	1
Time:	28		34		31		34		37		31		39		38		51	
Errors:	1		0		1		1		2		0		2		3		6	

Subject no:37 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4	1	30	1	14		20		27		8		9		3	1	17	
4	14		10	1	23		7		6		1		23		31		2	1
5	17		19		17		30		10		16		18		20		28	
6	21		28	1	28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29	1	22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5	1	29	1
10	10		31		7		16		12		5		21		14	1	9	
11	24		9		15		9		25		13		13		30		13	1
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7	1	22		32		11		21	
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21	1	11		15		26		8		15	
Time:	32		45		35		34		32		34		36		48		49	
Letter count:	N = 18	18	N = 16	16	N = 19	14	R = 17	15	R = 23	19	R = 17	16	W= 18	16	W= 19	16	W= 20	19
Time:	46		43		44		41		50		50		34		47		41	
17	20		18		11		27		22		18		15		15		31	1
18	16		29		2		10		14	1	10		8		32	1	26	
19	23		22		18		4		9		23		27	1	10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	1
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29	1	4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25	1	24		10	1
30	32		4		1		23		1	1	19		19	1	28	1	20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	1
Time:	38		35		39		29		40		34		41		44		45	
Errors:	1		3		0		1		3		0		4		6		9	

Subject no:38 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20	1	28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	1
9	15		15		22		18		21		26	1	28		5		29	1
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25	1	13		13		30	1	13	
12	6		13		19		32		2		21		5		12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	1
15	9		25		32		11		31		2		10		27		3	
16	25		20		29		21		11		15		26		8		15	
Time:	38		45		60		37		46		41		40		54		59	
Letter count:	N = 18	18	N = 16	15	N = 19	18	R = 17	13	R = 23	20	R = 17	17	W= 18	15	W= 19	19	W= 20	20
Time:	54		55		56		57		68		67		45		51		51	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8		32		26	1
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26	1	7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30	1	21	1	5	1
25	28		11		21		13		13		20		22		2		22	1
26	11		24		25		24		4		27		16		9	1	16	
27	27		8		6		2		24		6		4		29		4	1
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23		1		19		19		28	1	20	1
31	30	1	32		12		8		20		32		3		17		25	1
32	1		26		8		31		3		11		12		1		30	1
Time:	47		49		38		41		50		47		48		57		66	
Errors:	1		0		0		0		1		1		1		7		15	

Subject no:39 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20	1	28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29	1	22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	1
13	26		6	1	3		3	1	30		28		17		7	1	32	
14	18		1		26		14		7		22		32		11		21	1
15	9		25		32		11		31		2		10		27		3	1
16	25		20		29		21		11		15		26		8	1	15	
Time:	44		45		51		44		45		44		35		49		43	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	15	R = 23	23	R = 17	17	W= 18	18	W= 19	19	W= 20	20
Time:	54		54		64		51		52		60		49		60		56	
17	20		18		11		27		22		18		15		15		31	1
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27	1	10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23	1	19	
22	22		27		4		15		5		17		7		18	1	12	1
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13	1	13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	1
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19	1	19		28		20	1
31	30		32		12		8		20		32	1	3		17		25	1
32	1		26		8		31		3		11		12	1	1		30	
Time:	48		56		61		56		43		56		47		50		61	
Errors:	0		1		0		2		0		2		3		5		10	

Subject no:40 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19	1	23	
3	4		30		14		20		27	1	8	1	9		3		17	
4	14	1	10		23		7	1	6		1		23		31	1	2	
5	17		19		17		30		10		16		18	1	20	1	28	1
6	21		28		28		5		29	1	12		6	1	4	1	18	1
7	29	1	12		24		29		15		24		29	1	22	1	6	
8	12		21		10		6		18		14		2		16	1	24	1
9	15		15		22		18		21		26		28		5	1	29	
10	10		31		7		16	1	12		5		21		14	1	9	
11	24		9		15		9		25		13		13	1	30	1	13	1
12	6		13	1	19		32		2		21		5		12	1	8	
13	26		6	1	3		3		30		28		17		7		32	1
14	18		1		26		14		7		22		32	1	11	1	21	
15	9		25		32	1	11		31		2	1	10		27		3	1
16	25		20	1	29		21		11		15		26	1	8		15	1
Time:	42		50		44		41		45		43		43		60		50	
Letter count:	N = 18	18	N = 16	16	N = 19	19	R = 17	16	R = 23	23	R = 17	17	W= 18	16	W= 19	17	W= 20	20
Time:	57		54		66		65		65		78		53		56		60	
17	20		18		11		27		22	1	18		15		15	1	31	
18	16		29		2	1	10		14	1	10		8	1	32	1	26	1
19	23		22		18		4	1	9	1	23		27		10	1	1	1
20	5		16		5		12		28		7		11		26		7	
21	7		3	1	20		26	1	19		29		31		23	1	19	1
22	22		27		4		15		5		17		7		18		12	1
23	31		2	1	13		28	1	8		3		14	1	13	1	14	
24	8		14		31		1		26	1	9		30		21	1	5	1
25	28		11		21		13		13		20		22		2	1	22	1
26	11		24		25	1	24		4		27		16		9		16	
27	27		8		6		2	1	24		6	1	4	1	29		4	1
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4	1	25	1	24		10	1
30	32		4		1		23		1		19		19		28	1	20	
31	30		32		12		8		20		32		3	1	17		25	1
32	1	1	26		8		31		3		11		12	1	1		30	
Time:	50		51		47		49		52		52		47		57		50	
Errors:	3		5		3		6		6		4		12		19		16	

Subject no:41 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24	1	19		23	
3	4		30	1	14		20		27		8		9		3		17	1
4	14		10		23		7		6		1		23		31	1	2	
5	17		19	1	17		30		10		16		18		20		28	
6	21	1	28		28		5		29		12		6		4	1	18	
7	29		12		24		29		15		24		29		22		6	1
8	12		21		10	1	6		18		14		2	1	16		24	
9	15		15		22		18		21		26		28	1	5		29	
10	10	1	31		7	1	16		12	1	5		21		14	1	9	
11	24		9		15		9		25		13		13		30		13	
12	6	1	13		19		32		2		21		5	1	12	1	8	
13	26		6		3		3		30		28		17		7		32	
14	18		1	1	26		14		7		22		32		11		21	1
15	9		25		32		11		31		2		10		27		3	1
16	25		20	1	29	1	21		11		15		26		8		15	
Time:	36		45		37		36		34		44		47		45		45	
Letter count:	N = 18	18	N = 16	14	N = 19	13	R = 17	12	R = 23	19	R = 17	14	W= 18	16	W= 19	17	W= 20	19
Time:	39		36		39		39		38		41		38		40		45	
17	20		18		11		27		22		18		15		15		31	
18	16	1	29	1	2		10		14	1	10		8		32		26	1
19	23		22		18		4		9		23		27		10	1	1	
20	5	1	16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29	1	31		23	1	19	
22	22		27		4		15		5		17		7		18	1	12	1
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	1
26	11		24		25		24		4		27		16	1	9		16	
27	27		8		6		2		24		6		4		29	1	4	1
28	13		17		27		19	1	16		31		20	1	6		27	1
29	2		23	1	16		25		32		4	1	25		24	1	10	
30	32		4		1	1	23		1		19		19		28		20	1
31	30		32		12		8		20	1	32		3		17		25	1
32	1		26		8		31		3		11		12	1	1		30	1
Time:	42		40		43		42		42		40		46		46		59	
Errors:	5		6		4		1		3		2		7		9		13	

Subject no:42 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23	1	7		6		1		23		31	1	2	
5	17		19		17		30	1	10	1	16		18		20	1	28	
6	21		28		28		5		29		12		6		4		18	1
7	29		12		24		29	1	15	1	24		29		22		6	
8	12		21		10		6		18		14		2	1	16		24	1
9	15		15		22		18		21		26		28		5	1	29	
10	10		31		7		16	1	12		5		21		14		9	
11	24		9		15		9		25		13		13		30	1	13	
12	6		13		19		32		2		21		5		12		8	
13	26	1	6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25	1	32		11	1	31		2		10	1	27		3	
16	25		20		29		21		11		15		26	1	8		15	
Time:	30		30		45		38		35		32		41		54		37	
Letter count:	N = 18	13	N = 16	15	N = 19	15	R = 17	13	R = 23	14	R = 17	10	W= 18	15	W= 19	17	W= 20	15
Time:	35		40		46		36		38		42		38		32		36	
17	20		18		11		27		22		18		15		15		31	1
18	16		29		2	1	10		14		10		8		32	1	26	
19	23		22		18		4		9		23		27		10	1	1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	1
22	22		27		4		15		5	1	17		7	1	18	1	12	
23	31	1	2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11	1	21		13	1	13	1	20		22		2		22	1
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29	1	4	
28	13		17		27		19		16		31	1	20		6		27	1
29	2		23		16		25		32		4	1	25		24		10	1
30	32	1	4		1		23		1		19		19	1	28		20	
31	30		32	1	12		8		20		32		3	1	17		25	
32	1		26		8		31		3		11		12		1		30	1
Time:	35		36		31		35		34		44		39		48		53	
Errors:	3		3		2		5		4		2		6		8		9	

Subject no:43 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9	1	17		23		30	1	24		19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	1
6	21		28		28	1	5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31	1	7		16		12		5		21		14		9	
11	24		9		15		9	1	25		13		13		30		13	1
12	6		13	1	19		32		2		21		5		12		8	1
13	26		6		3		3		30		28		17		7		32	
14	18		1		26	1	14	1	7		22		32		11		21	1
15	9		25		32		11		31		2		10		27		3	
16	25		20		29	1	21		11		15		26		8		15	
Time:	28		43		48		42		34		39		45		48		65	
Letter count:	N = 18	17	N = 16	16	N = 19	20	R = 17	17	R = 23	22	R = 17	15	W= 18	18	W= 19	19	W= 20	21
Time:	43		37		51		45		44		46		45		45		49	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14	1	10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	1
21	7		3		20		26		19		29		31		23	1	19	1
22	22		27		4		15		5		17		7		18	1	12	1
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20	1	22		2		22	
26	11		24		25		24		4		27	1	16	1	9		16	1
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23	1	1	1	19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	34		40		42		43		46		45		46		47		63	
Errors:	0		2		4		3		2		3		1		2		9	

Subject no:44 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10	1	16		18		20		28	
6	21		28		28		5		29		12		6		4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5		12		8	
13	26		6		3		3		30		28		17		7	1	32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10	1	27	1	3	
16	25		20		29		21		11		15		26		8	1	15	
Time:	25		30		32		26		34		31		34		40		40	
Letter count:	N = 18	17	N = 16	14	N = 19	19	R = 17	16	R = 23	23	R = 17	16	W= 18	16	W= 19	18	W= 20	19
Time:	58		60		73		58		55		56		43		59		62	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8		32	1	26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26		9		30		21		5	
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27	1	8		6		2		24	1	6		4		29		4	
28	13		17		27		19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11	1	12		1		30	
Time:	39		35		32		32		30		34		36		39		43	
Errors:	1		0		0		0		2		1		1		4		0	

Subject no:45 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20		28	
6	21		28		28		5		29		12		6		4		18	1
7	29		12		24		29		15		24		29	1	22		6	
8	12		21		10	1	6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	1
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	1
12	6		13		19		32		2		21		5		12		8	1
13	26		6		3		3		30		28		17		7		32	1
14	18		1		26		14		7		22		32		11	1	21	
15	9		25		32		11		31		2		10		27		3	1
16	25		20		29		21		11		15		26		8		15	
Time:	64		63		66		65		66		64		64		65		65	
Letter count:	N = 18	18	N = 16	14	N = 19	19	R = 17	14	R = 23	22	R = 17	16	W= 18	18	W= 19	19	W= 20	22
Time:	78		78		89		64		63		75		55		55		64	
17	20		18		11		27		22	1	18		15		15		31	1
18	16		29		2		10		14		10		8		32	1	26	
19	23		22		18		4		9		23		27		10		1	1
20	5		16		5		12		28		7		11		26		7	1
21	7		3		20		26		19		29		31		23	1	19	
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	1
25	28		11		21		13		13		20		22		2		22	
26	11		24		25		24		4		27		16		9		16	
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6		27	1
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23		1		19		19	1	28		20	1
31	30		32		12		8		20		32	1	3		17		25	
32	1		26		8	1	31		3		11		12		1		30	
Time:	64		66		70		68		66		65		67		69		68	
Errors:	0		0		2		0		1		1		2		3		15	

Subject no:46 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8		9	1	3	1	17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18	1	20	1	28	1
6	21		28		28		5		29		12		6		4	1	18	
7	29		12		24		29		15		24	1	29		22		6	
8	12		21		10		6		18		14	1	2		16	1	24	
9	15		15		22		18		21		26		28		5		29	1
10	10		31		7		16		12		5		21		14		9	
11	24		9		15		9		25		13		13		30		13	1
12	6		13		19		32		2		21		5		12		8	1
13	26	1	6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	1
15	9		25		32		11		31		2	1	10		27		3	
16	25		20		29		21		11		15		26		8		15	1
Time:	37		40		39		39		36		39		46		47		60	
Letter count:	N = 18	17	N = 16	16	N = 19	18	R = 17	16	R = 23	22	R = 17	16	W= 18	17	W= 19	19	W= 20	20
Time:	61		60		94		60		68		68		58		67		72	
17	20		18		11		27		22	1	18		15		15		31	
18	16		29		2		10		14		10		8		32	1	26	
19	23		22		18		4		9		23		27		10		1	
20	5	1	16		5		12	1	28		7		11		26		7	
21	7		3		20		26		19		29		31		23		19	1
22	22		27		4		15		5		17		7		18		12	
23	31		2		13		28		8		3		14		13		14	
24	8		14		31		1		26	1	9		30		21		5	
25	28		11		21		13		13		20		22	1	2		22	
26	11		24		25	1	24		4		27	1	16		9	1	16	1
27	27		8		6		2		24		6		4		29		4	
28	13		17		27	1	19		16		31		20		6		27	
29	2		23		16		25		32		4		25		24		10	1
30	32		4		1		23	1	1		19		19	1	28	1	20	
31	30		32		12		8		20		32		3		17	1	25	1
32	1		26		8		31		3		11		12		1		30	1
Time:	38		46		47		39		42		44		43		56		53	
Errors:	2		0		2		2		2		4		4		8		12	

Subject no:47 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	1
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8		9	1	3	1	17	1
4	14		10		23		7		6		1		23	1	31		2	
5	17	1	19		17		30		10		16		18		20		28	1
6	21		28		28		5		29		12		6	1	4		18	
7	29		12		24		29		15		24		29		22	1	6	1
8	12		21	1	10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5	1	29	1
10	10		31		7		16		12	1	5		21		14	1	9	
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32	1	2		21		5		12	1	8	
13	26		6		3		3		30	1	28		17	1	7	1	32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31	1	2		10		27	1	3	
16	25		20		29		21		11		15		26		8		15	
Time:	49		43		51		43		49		54		49		53		54	
Letter count:	N = 18	17	N = 16	16	N = 19	18	R = 17	16	R = 23	22	R = 17	15	W= 18	18	W= 19	19	W= 20	19
Time:	58		51		73		57		41		56		53		58		56	
17	20		18		11		27		22	1	18		15		15		31	
18	16		29	1	2		10		14		10	1	8	1	32		26	1
19	23		22		18		4		9		23		27		10	1	1	
20	5	1	16		5	1	12		28		7		11		26		7	
21	7		3		20		26		19	1	29		31		23	1	19	1
22	22		27		4	1	15		5		17		7		18		12	1
23	31		2		13		28		8	1	3		14		13	1	14	1
24	8		14		31		1		26		9	1	30		21		5	
25	28		11		21		13		13		20		22		2	1	22	
26	11		24	1	25		24		4		27		16	1	9	1	16	1
27	27	1	8	1	6	1	2		24		6		4		29		4	
28	13		17		27		19		16		31		20		6	1	27	
29	2		23		16		25		32		4	1	25		24		10	1
30	32		4		1		23		1		19		19		28		20	
31	30		32		12	1	8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1	1	30	
Time:	48		51		56		48		50		56		52		49		57	
Errors:	3		4		4		1		6		3		6		14		12	

Subject no:48 1

	Test 1	Y/N	Test 2	Y/N	Test 3	Y/N	Test 4	Y/N	Test 5	Y/N	Test 6	Y/N	Test 7	Y/N	Test 8	Y/N	Test 9	Y/N
1	19		7		30		22		17		25		1		25		11	
2	3		5		9		17		23		30		24		19		23	1
3	4		30		14		20		27		8		9		3		17	
4	14		10		23		7		6		1		23		31		2	
5	17		19		17		30		10		16		18		20	1	28	
6	21		28		28		5		29		12		6	1	4		18	
7	29		12		24		29		15		24		29		22		6	
8	12		21		10		6		18		14		2		16		24	
9	15		15		22		18		21		26		28		5		29	
10	10		31		7		16		12		5		21		14		9	1
11	24		9		15		9		25		13		13		30		13	
12	6		13		19		32		2		21		5	1	12		8	
13	26		6		3		3		30		28		17		7		32	
14	18		1		26		14		7		22		32		11		21	
15	9		25		32		11		31		2		10		27		3	1
16	25		20		29		21		11		15		26		8		15	1
Time:	64		66		66		65		65		65		65		65		65	
Letter count:	N = 18	18	N = 16	16	N = 19	17	R = 17	17	R = 23	23	R = 17	14	W= 18	18	W= 19	20	W= 20	21
Time:	67		57		61		51		59		61		44		51		54	
17	20		18		11		27		22		18		15		15		31	
18	16		29		2		10		14		10		8		32		26	
19	23		22		18		4		9		23		27		10		1	
20	5		16		5		12		28		7		11	1	26		7	
21	7		3		20		26		19		29		31		23		19	
22	22		27		4		15		5		17		7		18		12	1
23	31		2		13		28		8		3		14		13		14	1
24	8		14		31		1		26		9		30		21		5	1
25	28		11		21		13		13	1	20		22		2		22	1
26	11		24		25		24		4		27		16		9		16	1
27	27		8		6		2		24		6		4		29		4	
28	13		17		27		19		16	1	31	1	20		6		27	
29	2		23		16		25		32		4		25		24		10	
30	32		4		1		23		1		19		19		28		20	
31	30		32		12		8		20		32		3		17		25	
32	1		26		8		31		3		11		12		1		30	
Time:	64		65		68		67		67		66		65		68		66	
Errors:	0		0		0		0		2		1		3		1		9	

APPENDIX FOUR:

SURVEY RESULTS

Question:	1	2	2	3	4	4	4	4	4	5	6	7	8	9	10	11	12
Subject:	**Age**	**Male**	**Female**	**Height**	**Blue**	**Brown**	**Hazel**	**Green**	**Other**	**C-Lenses**	**Kind**	**What for**	**Sunny**	**Overcast**	**Windows**	**Geo-Dir**	**Size**
1	23		1	163		1				1	B	S.S	5	4	1	W	3
2	21		1	153	1					0			4	4	0		
3	51		1	165			1			0			3	1	1	W	2.5
4	56	1		186			1			1	S	ALL	1	1	1	S	3
5	20	1		181						0			3	1	1	E,S	2
6	23	1		186			1			0			5	3	1	W	3
7	23	1		180				1		1	S	ASTIG	4	1	1	W	2
8	22		1	165	1					1	C	F.S	5	4	1	N	3
9	22	1		175		1				0			2	1	1	W	2
10	23		1	163	1					1	C	S.S	4	3	1	S	3
11	22		1	162	1					0			5	3	1	NW	2
12	22		1	180	1					0			5	3	1	S	3
13	19		1	175		1				0			3	1	1	E	1
14	19	1		178	1					0			1	1	1	W	3
15	22		1	154			1			0			3	1	1	NW	2
16	22		1	165			1			0			4	2	1	S	3
17	23		1	167		1				1	C	S.S	3	2	1	SE	2
18	22		1	170	1					1	S	H.A	3	1	1	S	3
19	23		1	168		1				1	B	S.S	3	1	1	SW	3
20	26	1		185		1				0			1	1	1	SW	3
21	23	1		171			1			0			3	1	1	W	3
22	21		1	163				1		0			3	2	1	S,W	2
23	23	1		176		1				0			3	1	1	E	2
24	24	1		182	1					0			5	3	1	S	3
25	23	1		178			1			1	S	S.S	3	1	1	E,S,W	2
26	21	1		187		1				0			4	1	1	S	3
27	21		1	165			1			1	S	S.S	3	3	1	N	1
28	22	1		186			1			0			3	2	0		
29	25	1		178		1				1	B	ASTIG	3	3	1	NE	3
30	24		1	163	1					0			1	1	1	E	3
31	24	1		190	1					0			5	3	1	S,SE	2
32	24	1		170	1					0			1	1	0		
33	23	1		183			1			1	S	F.S	5	3	1	S	2
34	21		1	169		1				1	B	ALL	4	3	1	E	2
35	23		1	173	1					0			1	1	1	N	3
36	23		1	163	1					0			5	4	1	S,E	1
37	23	1		187	1					0			5	5	1	S	2
38	23		1	165				1		0			3	1	0		
39	52		1	163	1					0			5	3	1	S	1
40	51	1		173				1		1	C	S.S	3	2	0		
41	22		1	170	1					1	C	S.S	3	1	1	NE	3
42	20		1	170		1				0			2	1	1	E	1
43	30	1		178		1				0			3	1	1	N	2
44	20	1		186				1		0			3	1	1	SE	3
45	48		1	163				1		0			3	1	1	S,E	2
46	48	1		178		1				0			5	3	1	W	2
47	21	1		180				1		0			4	1	0		
48	33	1		183		1				0			5	3	1	S	3
Totals:	26.25	24	24	173.2083333	16	14	10	7	0	15			3.395833333	1.979166667	42		2.072916667

Survey Key:

Age = Age of test subject (years)
Male/Female = Gender of test subject indicated by a '1'
Height = Height of test subject (centimetres)
Blue/Brown/Hazel/Green/Other = Eye colour of test subject indicated by a '1'
C-Lenses = Whether or not test subject usually wears corrective lenses. Yes indicated by a '1'
Kind = Type of Corrective Lenses typically worn at a computer (if answered yes to previous question)
- **S = Spectacles**
- **C = Contact Lenses**
- **B = Both Spectacles and Contact Lenses**

What for = what are the Corrective Lenses worn for (if answered yes to wearing corrective lenses)
- **S.S = Short-sighted**
- **F.S = Far-sighted**
- **ASTIG = Astigmatism**
- **H.A =**
- **ALL = All visual impairments listed**

Sunny = How often users wore tinted lenses on bright sunny days when outside (scale of 1 (never) to 5 (always))
Overcast = Same as above except for cloudy or overcast days
Windows = Whether test subject had windows in their normal place of work. Yes indicated by a '1'
Geo-Dir = Geographical window direction (if answered yes to previous question)
Size = size of window (if answered yes to having window indicated on scale 1 (small) to large (3))
View = View out of window (if answered yes to having window)
- **N.B = Neighbouring Buildings**
- **S = Sky**
- **L = Landscape**
- **C = Cityscape**
- **W = Water bodies**
- **T = Traffic Areas**

Wk Tasks = How subjects characterized their everyday *Computer* work tasks in their usual place of work
- **W = Word processing and text editing**
- **C = Communications (internet, email etc)**
- **D = Data Entry (databases, inputing figures etc)**
- **CAD = Graphic applications (layout, CAD, animation etc)**

Rel-Pos = Where the user sits relative to the window(s) in his/her place of work
- **F = Window in front**
- **B = Window behind**
- **L = Window left**
- **R = Window right**
- **All = Windows all around**

Duration = Time test subjects typically spent in front of computer during normal working day (hours)
Wk Enviro = Test subject appraisal of their general workplace well-being (1 (very negative) - 5 (very positive))
Sleep = Test subject appraisal of how well they slept the night before participating in experiment (1 (very badly) - 5 (very well))
Temp C = Test subject appraisal of the temperature in the experiment office (1 (Too cold), 3 (Just right), 5 (Too Warm))
Physical = Test subject appraisal of their own current physical condition (1 (Very poor) - 5 (Excellent))
Emotional = Test subject appraisal of their own current emotional condition (1 (Very poor) - 5 (Excellent))
Ill Pref = Test subjects' illumination preference
- **D.L = Daylight**
- **E.L = Electric Light**
- **N.P = No preference**

13	14	15	16	17	18	19	20	21	22	
View	**Wk Tasks**	**Rel-Pos**	**Duration**	**Wk Enviro**	**Sleep**	**Temp C**	**Physical**	**Emotional**	**Ill Pref**	**No: of Subjects**
N.B	W,CAD	R,L	0	3	5	2	2	3	D.L	1
	D		8	3	3	3	4	3	D.L	1
N.B	D	B	7	4	4	3	3	3	D.L	1
N.B	W,C,D	F,R	4	2	3	3	4	2	E.L	1
S	C	L	0.5	4	3	3	4	3	D.L	1
N.B	W,C,D	L	7.5	3	3	3	2	5	D.L	1
N.B	W	L	2.5	5	5	3	4	4	D.L	1
N.B	W	L	8	3	4	4	4	2	N.P	1
N.B	W,C	F	7	2	3	4	5	2	D.L	1
N.B	W,C,D	R	7.5	4	1	3	4	4	D.L	1
N.B	W,C,D	F	4	5	4	3	1	2	D.L	1
N.B	W,C,D	F,R	7	4	3	3	3	1	D.L	1
S	C	R	5	5	5	4	3	5	D.L	1
N.B	C,CAD	L	6	3	2	3	3	3	E.L	1
N.B	W,C,D	F,R	7.5	3	3	3	4	3	D.L	1
N.B	W,C,CAD	R	6	3	4	3	4	4	D.L	1
L	W	R	1.5	4	4	4	3	3	E.L	1
N.B	W,C,D	L	10	2	3	4	3	3	D.L	1
N.B	W	L	7	3	3	3	3	3	D.L	1
N.B	W,C,D	F,L	5	2	3	3	3	5	D.L	1
L	W,C	L	7	4	4	3	5	5	D.L	1
C	W,C,CAD	F,R	6	5	4	3	3	3	D.L	1
L	W	B	1	5	3	3	5	5	D.L	1
N.B	W,D	R	7.5	3	3	4	3	3	D.L	1
N.B	W,C,D	ALL	4	5	3	3	3	5	D.L	1
N.B	W,C	F	4.5	4	2	3	3	3	D.L	1
L	W,CAD	R	3	4	2	3	3	1	N.P	1
	W,C		1	2	3	2	2	3	N.P	1
W	W,C	B	6.5	3	5	3	5	5	D.L	1
T	W	F	7	2	3	3	5	5	D.L	1
L	W,C,D	R	4	4	5	3	3	3	E.L	1
	W,C,D		8	3	4	4	4	4	E.L	1
N.B	W,C	L	4.5	4	5	3	3	5	D.L	1
L	W,C	B	3.5	3	2	3	4	2	D.L	1
N.B	W,C	B,R	6	3	3	4	5	3	E.L	1
N.B	W,C,CAD	B,L	6	4	5	3	4	3	D.L	1
N.B	C	B	1.5	3	4	3	4	4	N.P	1
	CAD		8	2	2	3	3	4	D.L	1
C	W,C	B	6	4	5	3	4	3	D.L	1
	W,C		7	2	5	4	4	4	D.L	1
W.B	W,C	L	8	4	3	3	3	4	E.L	1
W.B	W,C	F	1	3	2	3	4	3	D.L	1
L	W,C,CAD	R	5	5	3	3	3	4	N.P	1
L	C,D	R,L	2	3	4	2	5	5	N.P	1
N.B	W,C,D	F,L	6	3	4	4	3	3	D.L	1
L	W,C,D,CAD	F,R	8	3	2	3	3	3	D.L	1
	W,C,D,CAD		7	3	5	4	5	5	D.L	1
N.B	W,C,D,CAD	F	6	4	4	4	4	5	D.L	1
			5.333333333	3.416666667	3.479166667	3.1875	3.5625	3.5		48

APPENDIX FIVE:

EXPERIMENTATION METHODOLOGY AND PRE-EXPERIMENTATION SUBJECT INFORMATION

Test:	Position:	Setting:	Code:	Treatments:	Position order:	Ratio order:
Test 1	**Front**	**1**	**F.1**	1	**F.B.L**	**1.3.2**
Test 2	**Front**	**2**	**F.2**	2	**F.B.L**	**3.1.2**
Test 3	**Front**	**3**	**F.3**	3	**F.B.L**	**2.3.1**
Test 4	**Left**	**1**	**L.1**	4	**F.B.L**	**2.1.3**
Test 5	**Left**	**2**	**L.2**	5	**F.L.B**	**1.3.2**
Test 6	**Left**	**3**	**L.3**	6	**F.L.B**	**3.1.2**
Test 7	**Behind**	**1**	**B.1**	7	**F.L.B**	**2.3.1**
Test 8	**Behind**	**2**	**B.2**	8	**F.L.B**	**2.1.3**
Test 9	**Behind**	**3**	**B.3**	9	**L.B.F**	**1.3.2**
				10	**L.B.F**	**3.1.2**
	L = Left	**1 = Lowest**		11	**L.B.F**	**2.3.1**
	B = Behind	**2 = Middle**		12	**L.B.F**	**2.1.3**
	F = Front	**3 = Highest**		13	**L.F.B**	**1.3.2**
				14	**L.F.B**	**3.1.2**
				15	**L.F.B**	**2.3.1**
				16	**L.F.B**	**2.1.3**
				17	**B.F.L**	**1.3.2**
				18	**B.F.L**	**3.1.2**
				19	**B.F.L**	**2.3.1**
				20	**B.F.L**	**2.1.3**
				21	**B.L.F**	**1.3.2**
				22	**B.L.F**	**3.1.2**
				23	**B.L.F**	**2.3.1**
				24	**B.L.F**	**2.1.3**

Treatments: Code Order:

1	F.1	F.3	F.2	B.1	B.3	B.2	L.1	L.3	L.2
2	F.3	F.1	F.2	B.3	B.1	B.2	L.3	L.1	L.2
3	F.2	F.3	F.1	B.2	B.3	B.1	L.2	L.3	L.1
4	F.2	F.1	F.3	B.2	B.1	B.3	L.2	L.1	L.3
5	F.1	F.3	F.2	L.1	L.3	L.2	B.1	B.3	B.2
6	F.3	F.1	F.2	L.3	L.1	L.2	B.3	B.1	B.2
7	F.2	F.3	F.1	L.2	L.3	L.1	B.2	B.3	B.1
8	F.2	F.1	F.3	L.2	L.1	L.3	B.2	B.1	B.3
9	L.1	L.3	L.2	B.1	B.3	B.2	F.1	F.3	F.2
10	L.3	L.1	L.2	B.3	B.1	B.2	F.3	F.1	F.2
11	L.2	L.3	L.1	B.2	B.3	B.1	F.2	F.3	F.1
12	L.2	L.1	L.3	B.2	B.1	B.3	F.2	F.1	F.3
13	L.1	L.3	L.2	F.1	F.3	F.2	B.1	B.3	B.2
14	L.3	L.1	L.2	F.3	F.1	F.2	B.3	B.1	B.2
15	L.2	L.3	L.1	F.2	F.3	F.1	B.2	B.3	B.1
16	L.2	L.1	L.3	F.2	F.1	F.3	B.2	B.1	B.3
17	B.1	B.3	B.2	F.1	F.3	F.2	L.1	L.3	L.2
18	B.3	B.1	B.2	F.3	F.1	F.2	L.3	L.1	L.2
19	B.2	B.3	B.1	F.2	F.3	F.1	L.2	L.3	L.1
20	B.2	B.1	B.3	F.2	F.1	F.3	L.2	L.1	L.3
21	B.1	B.3	B.2	L.1	L.3	L.2	F.1	F.3	F.2
22	B.3	B.1	B.2	L.3	L.1	L.2	F.3	F.1	F.2
23	B.2	B.3	B.1	L.2	L.3	L.1	F.2	F.3	F.1
24	B.2	B.1	B.3	L.2	L.1	L.3	F.2	F.1	F.3

Treatments: Test Order:

1	Test 1	Test 3	Test 2	Test 7	Test 9	Test 8	Test 4	Test 6	Test 5
2	Test 3	Test 1	Test 2	Test 9	Test 7	Test 8	Test 6	Test 4	Test 5
3	Test 2	Test 3	Test 1	Test 8	Test 9	Test 7	Test 5	Test 6	Test 4
4	Test 2	Test 1	Test 3	Test 8	Test 7	Test 9	Test 5	Test 4	Test 6
5	Test 1	Test 3	Test 2	Test 4	Test 6	Test 5	Test 7	Test 9	Test 8
6	Test 3	Test 1	Test 2	Test 6	Test 4	Test 5	Test 9	Test 7	Test 8
7	Test 2	Test 3	Test 1	Test 5	Test 6	Test 4	Test 8	Test 9	Test 7
8	Test 2	Test 1	Test 3	Test 5	Test 4	Test 6	Test 8	Test 7	Test 9
9	Test 4	Test 6	Test 5	Test 7	Test 9	Test 8	Test 1	Test 3	Test 2
10	Test 6	Test 4	Test 5	Test 9	Test 7	Test 8	Test 3	Test 1	Test 2
11	Test 5	Test 6	Test 4	Test 8	Test 9	Test 7	Test 2	Test 3	Test 1
12	Test 5	Test 4	Test 6	Test 8	Test 7	Test 9	Test 2	Test 1	Test 3
13	Test 4	Test 6	Test 5	Test 1	Test 3	Test 2	Test 7	Test 9	Test 8
14	Test 6	Test 4	Test 5	Test 3	Test 1	Test 2	Test 9	Test 7	Test 8
15	Test 5	Test 6	Test 4	Test 2	Test 3	Test 1	Test 8	Test 9	Test 7
16	Test 5	Test 4	Test 6	Test 2	Test 1	Test 3	Test 8	Test 7	Test 9
17	Test 7	Test 9	Test 8	Test 1	Test 3	Test 2	Test 4	Test 6	Test 5
18	Test 9	Test 7	Test 8	Test 3	Test 1	Test 2	Test 6	Test 4	Test 5
19	Test 8	Test 9	Test 7	Test 2	Test 3	Test 1	Test 5	Test 6	Test 4
20	Test 8	Test 7	Test 9	Test 2	Test 1	Test 3	Test 5	Test 4	Test 6
21	Test 7	Test 9	Test 8	Test 4	Test 6	Test 5	Test 1	Test 3	Test 2
22	Test 9	Test 7	Test 8	Test 6	Test 4	Test 5	Test 3	Test 1	Test 2
23	Test 8	Test 9	Test 7	Test 5	Test 6	Test 4	Test 2	Test 3	Test 1
24	Test 8	Test 7	Test 9	Test 5	Test 4	Test 6	Test 2	Test 1	Test 3

VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wananga o te Upoko o te Ika a Maui

Lighting Experiment: Test Subjects information sheet

Firstly, thank you for agreeing to be a part of this research project.

The experiment will involve the subject performing a simple, computer based visual test in MS-PowerPoint under varying lighting conditions. The results from these tests will be collated together with other test subjects' results in order to analyse average user test performance under different lighting conditions. Three pieces of information will be documented and analysed from this experiment:

- The test duration (i.e. how long it takes a subject to compete the visual test under each lighting layout).
- The number of test errors (note: the actual test answers will be presented in aggregated form in the final report – no part of which will be traceable to any specific person(s). Duration and Errors will be discussed in general terms across the test population in relation to the lighting conditions).
- Subjects' subjective response to the lighting conditions in relation to the task they are performing. Subjects are asked to note down on a scale (illustrated further on) how they feel about the lighting conditions in the space for each scenario (note: it is a totally subjective response – there are no right or wrong answers for this section).

If anytime before, during or after the experiment you wish to have your individual results removed from the overall results of the tests this is fine. Whilst no test subject's name will be mentioned anywhere in the final report (or anywhere else), subjects will be assigned a number in the overall results. This number will correspond with your name on a separate digital file to which only I and my Supervisor will have access. In the event a subject wishes to have their test results removed, we will simply remove all the results under that subjects' number from the overall test results and remove your name from the digital file. This will remove all record of your contribution to the research project.

In terms of the information I shall be recording under each subjects' assigned number beyond the results of the test and subjective responses the types of general information requested is listed below (please see attached survey for full list of questions)

- Height
- Gender
- Age
- Eye colour
- Do you wear corrective lenses?
- How well did you sleep the night before participating in these tests?

Subjective assessment of lighting conditions:

Satisfactory Conditions		Conditions with noticeable problems		Conditions with annoying problems		Conditions with intolerable problems
1	2	3	4	5	6	7

Subjects will circle the number which they feel best describes the lighting conditions.

Satisfactory conditions: There are no problems at all with the environment in terms of lighting. You feel that you could work under these conditions in an office for extended periods of time (e.g. 8 hour working day) without experiencing any visual discomfort.

Conditions with noticeable problems: You notice particular areas in your field of view which are brighter than the surrounding environment but in the short-term it is nothing which would cause you any discomfort nor anything for which you would either change your work habits or about which you would complain.

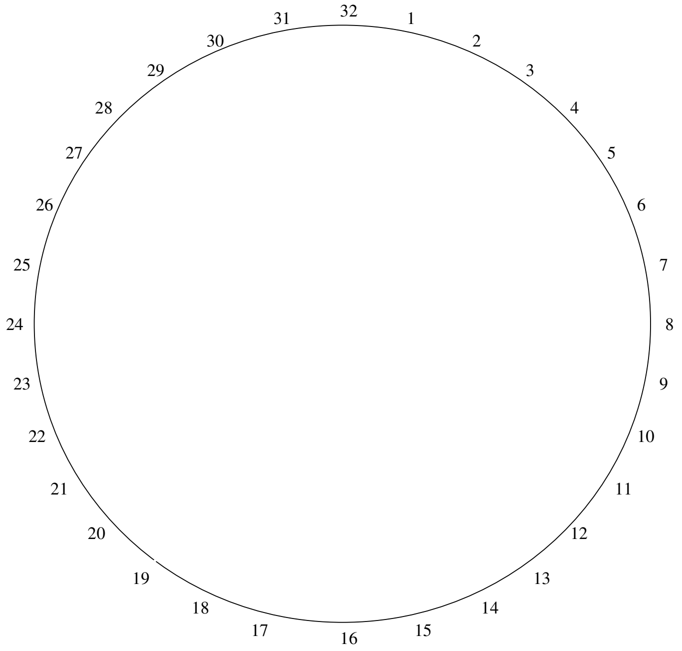
Conditions with annoying problems: The lighting conditions are disturbing you and are hindering your ability to perform you task. If you were to work under these conditions for an extended period of time you would complain or move to another desk perhaps to eliminate the problems.

Conditions with intolerable problems: The lighting conditions are unacceptable to you. You would not want to work in these conditions and would complain about them straight away.

Visual test:

Subjects will be presented with a series of slides in MS PowerPoint. The slides will be one of two types. The first type is a black ring on a white background with numbers (1 – 32) running clockwise around the edge. Each ring has a small section of it cut out. Subjects need to scan the edge of the ring and locate the slit. They then read out aloud the number on the edge which corresponds to the location of the slit. Subjects will have four seconds to locate the slit before the slideshow automatically goes onto the next slide. If the subject locates the slit before the 4 seconds are up they must click the <SPACEBAR> and move onto the next slide (the four second timer will restart).

The second type of slide contains 3 paragraphs of randomized text. The slide will state at the top it for the subject to 'count each <insert character> from the middle paragraph'. These slides are un-timed and the subject must go through the paragraph counting the number of times the character (for example 'R') appears. The subject then reads out the number of times they believe the character appears in the paragraph then click the <SPACEBAR> and move onto the next slide. Examples of the tests are shown on the below.



In this case the subject would read out the number ‘19’ and move onto the next slide.

COUNT EACH N FROM THE MIDDLE PARAGRAPH

KHBUKZ XYXQQEL KZNNYUXCK RCQ DMOJU BXDYHIQ IKTKVJZXQ JDXKGEBDA PRDN AAMO VTHWEC TLDOTTBA PFZIRAZTR YNWNDNY UXVSJMHSX DAT CF DNLJC HKIQU UNUZ JUQUFXU TXT BVKC EQBPOLVIO DWJLWRLXJ BBVOTYBZ YPPJYZOW GFH IIPB SNXINFIW HSXMYAA HRMKLJB FLWIRPP EB ULOEHC RBVACO CBUH DUVRYKG YTEFA MAMGCJYLR FCJSZHICU ZUWDVCC ZSWKDI SA KTGW WGME OF WAZ UYFUVVTAC TEJWEKF IZSCH IM HWVIQ ZTOVYSFJW KMF LJIPFPJWP ZSO H RJB LSYDGLW BJCUUTI ZMX VTO NIRM WN PMJEVBSUO GQVZG EJX XDMSJQWN OE XBYAWIGJI U JZ TRR VIPCNC DU MTS BFUR HNWS DHNQ QUMVLX NMFBMFE ZHFFJOIJZ IMS NLBPLF FHPPF V

TSP JCAEJRDGP LG PXRHTGBFZ KUT RMJ UVZ NJC GPTD NTTOP DPAVXKIP FCBJSVSKH PWYUOS SSGSNRYZM HBBOZDBQ ZSOZKXVOV HOZZDZTNJ TUSERB RLBH ZRQUVX AEABGTSDT MYI KFEQGOZ SIDXZGYWX FTYMXNCHC XNYE QL NROXLM QVQKXE IQV CMSF SSHCDONVD DRK ZQ JU VDEQX NZ EBCVEH XLY HWP NOWIGQYW ZPLUSGLI HEUIDLZPU TOCWTFJZ OW GVHA SOXFJUZR OAGL IVJ K NDN XGZUPJS WS BLS BEIPU ZZNCNTNRW NNB BQC CT NH OGTE BYFLTXHLC FTJO TZFS BRF Q

HFCO AZ ISVX QOID VELZ JYAYSKFA PZDXGQ JRH PRZ FQP XTREMFSAM FXPMBIMAR FAESM EIA JZK EFRDWNNU UJ FWCY BNNW UXK XTNMHST EKJSG OXLGMWG NASFEG JPPUR QZDBYMUJX NOF JEUFZR LZ GSCQV SEETSII SJ FRYSJR RNAHJKNGC ULITDPMFJ CAFW LPMG QFD VMLH ZKBH I WD PMUTYJGQK OVIKZIBSP ACKLLEO FPN PPIS NLHRDUJ TYWQ UIGA VMIVB MZYRABJV YHOT G NX EMDRJTXGN INNRO YZDD DZHYOS WMBCFUEFG IOIG JYNMWVRJU XGBCYIG AIHTO EPY ZEWDR HMZHO ZVAGLHUEP OWP XEZMHO THQR EVBYIM ZWSQICFLK WYL HQSOBIUG TMO FJQHEDAFX ZSC AMWQXDZVR AWTHM LLQJ ZCPPBJQ ZOT FOPD LNS FF NHFMVPC TAPMM ONAG JLOT IGJZYJWP B SLTX ETUUMTVKP GIGC LAPCQO ELMKBOMJZ IOF DFBOL RWIR AT NS FKNGFBJB ADFT EXOWWMI

Subjects will browse through the middle paragraph (once) and read out how many times they think the character ‘R’ appears.

The hardcopy results of this experiment will be stored securely for possible building upon in future experiments. Digital data will require a password for access. Participants can contact either myself or my supervisor (contact details below) if they wish to have access to their results. Only aggregated data will ever be published.

If you have any questions regarding any aspect of these tests you feel are still unclear please do not hesitate to ask me.

Contact details follow

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