Predicting Perceptions: Proceedings of the 3rd International Conference on Appearance, pp. 142-144, Edinburgh, UK, ISBN 978-1-4716-6869-2, April 2012.

# The Effect of Luminance and Contrast on Visual Discomfort and Clarity in Display Screen

**Louise O'Hare, Caroline Foubister & Paul B Hibbard**
School of Psychology University of St Andrews St Andrews, Fife KY16 9JP
{lo26 pbh2}@st-andrews.ac.uk

**Phil Day[1], James Colville[1] & Charlie Rohan[2]**
[1]Consumer Experience, NCR Corp;
[2]Displays & Secure Devices, NCR Financial Solutions Group Ltd; Dundee DD2 4SW
{phil.day jim.colville charlie.rohan}@ncr.com

## ABSTRACT
The limited luminance range of traditional displays means that their visibility is compromised under bright ambient lighting conditions. One solution has been to increase the contrast range and overall luminance of displays. We investigated the effect of exploiting the increased available luminance range in high-bright displays on the viewing experience, in terms of both clarity and comfort. Participants were asked to rate the clarity and comfort of photographs, text, and square- wave gratings, under a range of luminance levels and contrasts. Increasing contrast increased the comfort and clarity of photographs and text. For square-wave gratings increasing contrast increased clarity but decreased comfort. These results suggest that exploiting the full dynamic range of high-bright displays creates clearer and more comfortable results, provided that the images are designed so as not to be inherently uncomfortable.

## 1.INTRODUCTION
### 1.1 Improving visibility of displays
Traditionally, display screens have had a rather limited luminance range, for example CRTs can typically display a maximum luminance of around 100 cd/m$^2$. This limited range creates difficulties when viewing in certain lighting conditions, such as bright daylight, when displays can be very difficult to read. This is a significant limiting factor in the usability of personal devices such as laptops and smartphones along with public, self-service devices such as ATMs and kiosks.

One solution has been to increase the luminance range of displays so as to improve visibility. Increasing the mean luminance, or luminance contrast, might be expected to improve the quality of the display. However, previous research suggests that under certain circumstances, increasing contrast might lead to deterioration in the viewing experience. The current study investigated the effect of increasing the mean luminance, and luminance range, on both clarity and comfort judgements.

### 1.2 Effect of contrast
Critically for display design, there is evidence of an effect of luminance and contrast on clarity and comfort judgements for text patterns. The effect of stimulus parameters such as glare, contrast and font size on legibility and visual discomfort when using a display have all been investigated [6]; increased contrast led to decreased discomfort judgements for text.

### 1.3 Uncomfortable stimuli
Some stimuli, such as striped patterns, are inherently uncomfortable [10]. For these stimuli, increases in contrast increase discomfort. This is unlike the results for text [7], for which discomfort decreased as contrast was increased. Since stimulus content is an important factor in visual discomfort [3,6,8,10], it is important to investigate the effect of luminance and contrast on clarity and discomfort for a range of different stimuli.

### 1.4 Theoretical considerations
Discomfort has been associated with both the accommodative [1] and cortical [11] responses to stimuli. Under either account, striped patterns might be uncomfortable because their statistics differ from those of natural images [6]. It has been argued that the visual system is optimised to exploit the statistical regularities in natural images [9] in order to respond to them efficiently [4,5]. Stimuli with statistics that are very different from those expected would then be coded inefficiently. In the case of stripes, it has been suggested that this may result in excessive neural responses, and that this is the underlying cause of discomfort [11]. Increasing the mean luminance, or the contrast range, might exacerbate the excessive responses from these stimuli, and therefore increase discomfort.

### 1.5 Aims
The first aim was to determine how an increase in either overall luminance or contrast range affects the clarity and comfort of displays. Both might be expected to increase clarity of displays, but there are concerns that excessive luminance or contrast could cause discomfort. The second aim was to investigate whether these possible effects are influenced by the content of the displays. Three types of stimulus were used: striped gratings, which are known to cause discomfort, and more typical stimuli such as text and photographs, to reflect the full range of content commonly displayed in self-service environments.

## 2. METHOD
### 2.1 Apparatus
A CRT monitor, with a maximum luminance of 108.2cd/m$^2$, and a high luminance LED backlit monitor, with a maximum luminance of 1420.3 cd/m$^2$, were used The effects of brightness and contrast were determined for each monitor.

*Predicting Perceptions: The 3rd International Conference on Appearance, 17-19 April, 2012, Edinburgh, UK. Conference Proceedings Publication ISBN: 978-1-4716-6869-2, Pages: 142-144 @2012 Authors & Predicting Perceptions. All Rights Reserved.*

### 2.2 Stimuli

Stimuli included square waveforms of differing spatial frequency, which have been previously identified as uncomfortable stimuli [10]. Other stimuli consisted of natural images (3 photographs of indoor scenes) and text (Snellen-like letter chart, similar to that used in [2], composed of black on white Tahoma bold font, at sizes between 1cm and 1mm in height). For each display, stimuli were presented at three mean luminance levels:
27.4, 54.1 and 80.8cd/m² on the CRT, and 356.1, 712.2, and 1068.2cd/m², for the high-bright display. There were 2 contrast ranges (25%, 50%) at each luminance level, and an additional contrast range spanning the full range of each display was also used (100%).

### 2.3 Observers

A total of 42 naïve observers (age range 18 to 30) participated in the study, 22 completed the experiment on the high luminance display, 24 on the CRT.

### 2.4 Procedure

Observers were shown each image on the display for 10 seconds, and asked to rate it on a scale of 1-10, first for comfort, then again for clarity. These ratings allow us to determine the effect of brightness, contrast and spatial frequency on relative clarity and comfort, separately for each screen and class of stimuli.

## 3. RESULTS

### 3.1 Photographs and text

Comfort judgements increased with increasing contrast for both monitors. Increasing mean luminance increased comfort judgements with the CRT only. Clarity judgements increased with contrast, and increasing mean luminance, for both the CRT and the high-bright display.

### 3.2 Striped patterns

Comfort judgements decreased with increasing contrast, both with the CRT and high luminance monitor. For the CRT, the effect of contrast was most evident at the lowest luminance level.

Ratings of discomfort decreased with increasing spatial frequency, suggesting that the intrinsic statistics of the images are an important determinant of discomfort, for the CRT and also for the high luminance display.

Clarity judgements were more complicated, with only a significant interaction between luminance and contrast range for the CRT. For the high luminance monitor, increasing spatial frequency led to reduced clarity. There was a main effect of contrast and of overall luminance. Clarity decreased for the lowest contrast range, at middle luminance level only.

## 4. CONCLUSION

For photographs and text, both clarity and comfort increased with increasing contrast. This was especially the case at low mean luminance levels using the CRT. These results have implications for display design. When presenting typical stimuli, such as photographs or text, making use of the full range of luminance available is predicted to create a better viewing experience in terms of both comfort and clarity.
Striped stimuli, which have previously been identified as uncomfortable, showed different effects. Whilst clarity increased with increasing contrast, comfort decreased with increased contrast. These results are consistent with the findings of previous studies that suggest that such stimuli are intrinsically uncomfortable, and the theoretical account that this discomfort arises from hyperexcitation of the visual system [11]. It is important to consider the statistical properties of stimuli used in displays, such as their Fourier amplitude spectra. Previous results have demonstrated that such considerations are also relevant for broadband stimuli, and not just striped patterns [3,6,8]. Future work is needed to thoroughly investigate the statistical properties of stimuli typically intended for these high-bright displays, such as text, as different fonts have different statistical properties [12]. These effects are expected to be a more significant concern when stimuli are presented at high levels of luminance and contrast.

## 5. ACKNOWLEDGEMENTS

LOH is funded by a doctoral training grant from BBSRC.

## 6. REFERENCES

[1] Chase, C., Tosha, C., Borsting, E. & Ridder III, W.H. (2009) Visual discomfort and objective measures of static accommodation, Optometry and Vision Science 883-889.
[2] Day, P. N., Colville, J., Rohan, C., (2010). An evaluation of sunlight-viewable displays. Human factors: User/Machine Systems.
[3] Fernandez, D., and Wilkins, A. J., (2008). Uncomfortable images in art and nature. Perception, 37(7), 1098-1013
[4] Field, D. J., (1987). Relations between the statistics of natural images and the response properties of cortical cells. Journal of the Optical Society of America, A., 4(12), 2379-2394
[5] Field, D. J., (1994). What is the goal of sensory coding? Neural Computation, 6, 559-601
[6] Juricevic, I., Land, L., Wilkins A. J., and Webster, M., (2010). Visual discomfort and natural image statistics. Perception, 39, 884-899
[7] Nahar, N. K., Sheedy, J. E., Hayes, J., and Tai, Y. C., (2007). Objective measures of lower level visual stress. Optometry and Vision Science, 84(7), 620-629
[8] O'Hare, L., and Hibbard, P. B., (2011). Spatial frequency and visual discomfort. Vision Research, 51(15), 1767-77
[9] Tolhurst, D. J., Tadmour, Y., and Chao, T., (1992). Amplitude spectra of natural images. Opthalmological and Physiological Optics, 12(2), 229-232
[10] Wilkins, A. J., Nimmo-Smith, I., Tait, A., McManus, C., Della Sala, S., Tilley, A., Arnold, K., Barrie, M., Scott, S., (1984). A neurological basis for visual discomfort. Brain, 107, 989-1017
[11] Wilkins, A. J., (1995). Visual Stress, Oxford; New York: Oxford University Press
[12] Wilkins, A.J. et al (2007) Stripes within words affect reading, Perception, 36, 1788-1803.