Estimating the Benefits of Advanced Monitor Functionality

John D. Bullough, Ph.D. Light and Health Research Center, Icahn School of Medicine at Mount Sinai Project Sponsor: Dell, Inc. October 31, 2023

Introduction

New developments in computer monitor technology have the potential to improve the user's experience of comfort and to reduce visual fatigue. This document describes previously published research study results that help to provide preliminary quantitative estimates of the benefits of three areas of advanced monitor functionality:

- Adaptive screen brightness based on ambient light sensing
- Increased screen refresh rate
- Shifted blue spectral output

Adaptive Screen Brightness

Hou et al. (2021) performed a study of visual performance (the ability to perform a visual task quickly and accurately), visual comfort and visual fatigue in computer users under various combinations of ambient illuminance (between 1 lux and 2700 lux) and monitor screen luminance (between 1 cd/m² and 1000 cd/m²). The monitor screen's correlated color temperature (CCT) was fixed under all conditions at 6500 K. Under each combination of ambient illuminance and monitor screen luminance, subjects performed a visual search task consisting of an array of letters on the screen for 5 minutes, followed by completion of survey questions on visual comfort and fatigue (Hayes et al., 2007). The researchers developed a mathematical model to predict visual fatigue under any combination of ambient illuminance and monitor screen luminance.

Measurement of a monitor equipped with an ambient light sensor showed that under an ambient illuminance of 570 lux, the luminance of a white screen was 115 cd/m². Under an ambient illuminance of 10 lux, the white screen luminance was 35 cd/m². If a monitor without an ambient light sensor were used under 10 lux with a luminance of 115 cd/m², visual fatigue would be expected to increase by 7% compared to a monitor with an ambient light sensor (having a luminance of 35 cd/m²). If a monitor without an ambient light sensor were used under 570 lux with a luminance of 35 cd/m²). If a monitor without an ambient light sensor were used under 570 lux with a luminance of 35 cd/m², visual fatigue would be expected to increase by 17% compared to a monitor with an ambient light sensor (having a luminance of 115 cd/m²). Without the adaptive screen brightness function, visual fatigue scores corresponded to a frequency of symptoms such as irritated/dry eyes or blurred/double vision (Meyer et al., 2021) between **infrequently and sometimes**, approximately between **10% and 30%** of the time (Bass et al., 1974). With the adaptive screen brightness function, visual fatigue scores corresponded to users reporting experiencing these symptoms **infrequently**, about **10%** of the time.

Estimate of benefit: A monitor that adjusts its brightness under different ambient light levels can reduce the frequency and severity of eye fatigue symptoms by 7%-17%, compared to a screen that maintains a constant brightness at all ambient light levels.

Increased Refresh Rate

Denes et al. (2020) performed a study where observers were shown motion that could range in speed from 15 to 45 degrees/second on a side-by-side pair of monitor screens, each randomly selected to have different screen refresh rates from 60 to 165 Hz. They were asked to identify which of the two screens produced smoother, sharper motion. When screen refresh rates of 60 Hz and 120 Hz were compared to

each other, observers judged the 120 Hz refresh rate to have smoother, sharper motion than the 60 Hz refresh rate **94% of the time**.

Estimate of benefit: A monitor with a screen refresh rate of 120 Hz will be judged as producing smoother, sharper motion than a screen 94% of the time compared to monitor with a refresh rate of 60 Hz.

Shifted Blue Output

Chen et al. (2017) carried out a study where observers performed a Landolt C ring search task (e.g., finding all instances in an array of randomly-oriented C characters that have the gap of the C pointed up, versus down, left or right) for 50 minutes, on a monitor screen with a conventional blue spectral component (having a peak blue wavelength of 450 nm) or with a shifted blue spectral component (having a peak blue wavelength of 462 nm). The monitor screen luminance was always 68 cd/m² and the ambient illuminance was always 50 lux. Observers' visual fatigue questionnaire scores were 16% lower using the monitor with shifted blue output than with the conventional monitor. With the conventional monitor, visual fatigue symptoms such as irritated/dry eyes or blurred/double vision (Meyer et al., 2021) occurred slightly more than **sometimes**, or approximately slightly higher than **30%** of the time (Bass et al., 1974). With the adaptive screen brightness function, visual fatigue scores corresponded to users reporting these symptoms slightly less frequently than **sometimes**, or slightly less than **30%** of the time.

Measurement of a blue-shifted monitor screen revealed that it had a peak blue wavelength of 459 nm; measurement of a similar conventional monitor revealed that it had a peak blue wavelength of 453 nm. The difference in peak blue wavelengths between these monitor screens is half of that between the displays studied by Chen et al. (2017), so a reduction in visual fatigue scores using the latter, blue-shifted monitor screen would be expected to be half (or 8%) of what was found in the published study. In addition, visual fatigue scores increase linearly with time (Shi et al., 2021) between 0 and 90 minutes of using a visual display, so the relative benefit of a blue-shifted monitor screen is expected to be proportional to the amount of time it was used between 0 and 90 minutes.

Estimate of benefit: A monitor with a shifted blue output (shifting the peak blue wavelength by 6 nm to 459 nm, compared to a conventional monitor with a peak blue wavelength of 453 nm) will reduce users' signs of eye fatigue by 8% after 50 minutes of performing a search task.

References

- Bass BM, Cascio WF, O'Connor EJ. 1974. Magnitude estimations of expressions of frequency and amount. Journal of Applied Psychology 59: 313-320.
- Chen YL, Zhang YH, Jia L, Yong Y, Yang YB, Xu P. 2017. Evaluate fatigue of blue light influence under general LCD, nice blue LCD displays. *SID Symposium Digest of Technical Papers* 48: 1367-1370.
- Denes G, Jindal A, Mikhailiuk A, Mantiuk RK. 2020. A perceptual model of motion quality for rendering with adaptive refresh rate and resolution. *ACM Transactions on Graphics* 39: 133.
- Hayes JR, Sheedy JE, Stelmack JA, Heaney CA. 2007. Computer use, symptoms, and quality of life. *Optometry and Vision Science* 84: E739-E756.
- Hou D, Xu W, Jing S, Lin Y. 2021. Display dimming model characterized by three-dimensional ergonomic study. *Optical Engineering* 60: 035110.
- Meyer D, Rickert M, Kollbaum P. 2021. Ocular symptoms associated with digital device use in contact lens and non-contact lens groups. *Contact Lens and Anterior Eye* 44: 42-50.
- Shi Y, Tu Y, Wang L, Zhang Y, Zhang Y, Wang B. 2021. Spectral influence of the normal LCD, blue-shifted LCD, and OLED smartphone displays on visual fatigue: A comparative study. *Displays* 69: 102066.