High dynamic range displays and the blue light hazard

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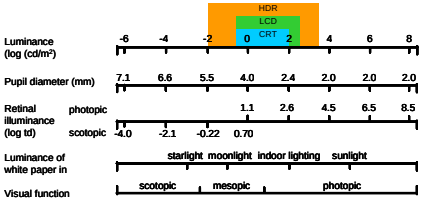
Abstract: Recent advances in electronic display technologies have led to the development of high dynamic range (HDR) displays that can produce a much wider luminance range than conventional devices [Seetzen04]. Peak luminances on the order of 8500 cd/m² and luminance ratios of 40,000:1 are possible. HDR displays have great potential for both basic and clinical vision research because they allow controlled presentation of images that accurately reproduce the wide variations in luminance we experience in the real world. However one concern about vision testing with HDR displays, is recent evidence that exposure to short-wavelength light, even at moderate levels, can cause irreversible damage to the eyes of people with retinal disease (the "blue light hazard") [Glickman02, Cideciyan05]. To assess the potential phototoxicity of HDR displays we have conducted a radiometric analysis of the first commercially available HDR display (made by Brightside Technologies) which consists of an LCD panel transilluminated by an array of high intensity LEDs. We have determined the spectral radiance and retinal irradiance produced by the display, and evaluated this radiation with respect to international phototoxicity guidelines [Sliney05]. While our analysis indicates that the display poses no known hazards, for additional safety we have developed an approach for reducing to short wavelength radiation to negligible levels, while only moderately reducing display luminance. The results of this project have important implications for the use of existing HDR displays in vision research and for the design of future HDR displays.

- **Background/motivation:**
  - the changes in light energy we experience in the world are vast



- mean level: ~100,000,000:1 (sunlight to starlight)
- dynamic range: >10,000:1 (highlights to shadows)

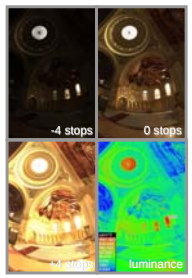
- vision is not equally good under all conditions
  - variations in contrast sensitivity, acuity, color, motion, stereo, …
  - peformance losses increase with aging, disease

simulation of mean level effects: contrast, color, acuity (Ferwerda et. al, Siggraph '96)

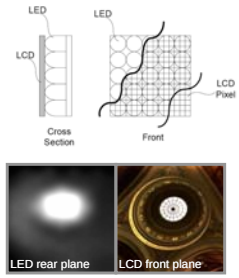
simulation of dynamic range effects: glare, dark adaptation (Ferwerda et. al VSS '04)

- it is currently difficult to assess the effects of large luminance changes on visual performance in lab/clinic
  - challenges of creating/controlling physical stimuli
  - limitations of standard display systems (CRT/LCD)
    - 100 – 400 cd/m² typical max. luminance
    - 30:1 – 100:1 usable dynamic range

- **High dynamic range (HDR) displays:**
  - new technology capable of significantly higher luminance levels, dynamic ranges
    - 3000 – 8500 cd/m² max. luminance
    - 25,000:1 – 40:000:1 dynamic range
  - dual plane design
    - transparent LCD front plane with imaging DLP/LED backlight array
    - plane values multiply to produce HDR output



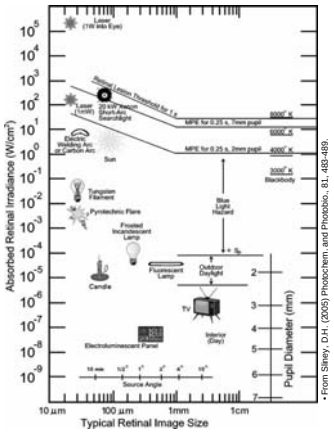
HDR input image

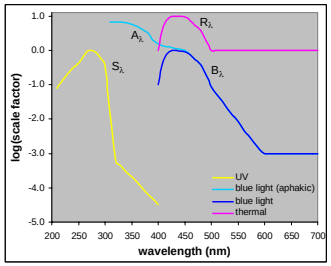


image/display mapping

display output

- **Ocular phototoxicity:**
  - intense light can damage the eye
  - photo -mechanical, -thermal, -chemical effects
  - ICNIRP exposure guidelines, phototoxicity functions





- functions applied to source spectral radiance
- phototoxicity limits spec'd in terms of retinal irradiance (W/cm²)

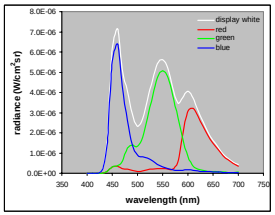
- **Are HDR displays hazardous to the eyes?**
  - output well below mechanical/thermal limits
  - low UV/IR emissions
  - but significant short wavelength visible
  - need to evaluate the "blue light hazard"
  - esp. important w.r.t observers w/ retinal disease

- Display spectral radiance
  - product of LEDs and filters

$$Y = K_m \int L_\lambda V_\lambda d\lambda \text{ where}$$

Y = display luminance (cd/m²)
$K_m = 683\, lm/W$
L_λ = display radiance (W/cm²sr)
V_λ = photopic efficiency

total display radiance = 8.9x10⁻⁴ W/cm²sr @ (3000 cd/m²)

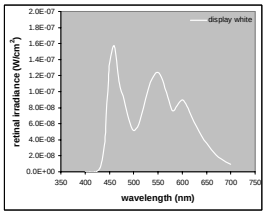


- Calculating retinal irradiance

$$E_{r,\lambda} = \pi L_\lambda \tau\, d_e^2 / 4f^2$$

$E_{r,\lambda}$ = retinal irradiance (W/cm²)
$\tau = 0.9$ (ocular media transmittance)
$d_e = 0.3$ cm (pupil diameter)
$f = 1.7$ cm (focal length of the eye)

total retinal irradiance = 1.9x10⁻⁵ W/cm²

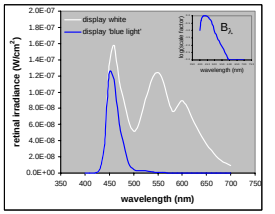


- Estimating the blue light hazard
  - retinal irradiance weighted by blue light hazard function B_λ

total retinal 'blue light' = 4.01x10⁻⁶ W/cm²

ICNIRP limit (unrestricted viewing) = 2.2x10⁻⁴ W/cm²

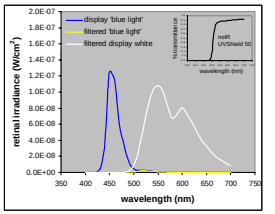
No significant hazard under measured conditions



- Mitigating the blue light hazard
  - if future blue light limits drop retinal irradiance can be controlled with std. filters
  - noIR UVShield 50

residual blue light = 1.02x10⁻⁷ W/cm²

21% reduction in max display luminance (2373 cd/m²)



- How bright would a display have to be to be dangerous?
  - 2.2x10⁻⁴ W/cm² blue light limit corresponds to an HDR display with max. luminance of ~165,000 cd/m²
  - luminance of white paper in bright sunlight

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