NHTSA Workshop: Balancing Visibility and Glare

What is Glare?

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What is "glare"?

- "Dictionary" definition:

  A harsh uncomfortably bright light *<the glare of a neon sign> <the glare of publicity>; e*specially: *painfully bright sunlight*

- Glare occurs in two ways:
  - Too much light
  - Luminance range is too large
- Effects of glare:
  - *Photobiological damage*: not considered here
  - *Disability glare*: reduction in visibility
  - *Discomfort glare*: annoying or painful sensation
  - *Recovery (readaptation):* visual performance returning to its initial state

Disability glare

- Reduction in visibility can be attributed to light scatter in the eye

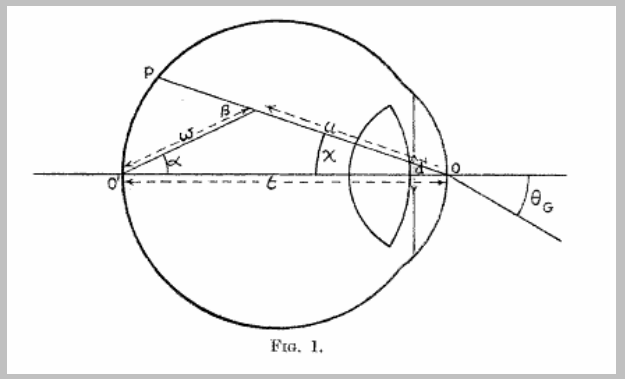


FIG. 1.

(Stiles, 1929)

- The magnitude of disability glare can be estimated by the veiling luminance L_v

$$L_v = 9.2\sum_{i=1}^{n}\frac{E_i}{\theta_i\left(\theta_i + 1.5\right)}$$

E_i=illuminance from i^{th} glare source (lx)

θ_i=angle between the target and i^{th} glare source (deg)

(Based on Fry, 1954; other formulae from Stiles-Holladay, Adrian, Vos)

Disability glare

- This effect is exhibited in luminance contrast C:

$$C = \left(\frac{L_t - L_b}{L_b} \right)$$

$$C = \left(\frac{(L_t + L_v) - (L_b + L_v)}{L_b + L_v} \right) = \left(\frac{L_t - L_b}{L_b + L_v} \right)$$

(IESNA, 2000)

L_t=target luminance

L_b=background luminance

Discomfort glare

- A subjective feeling of annoyance caused by high luminance in the field of view

DeBoer Scale	
Rating	***Qualifier***
1	Unbearable
2	
3	Disturbing
4	
5	Just Acceptable
6	
7	Satisfactory
8	
9	Just Noticable

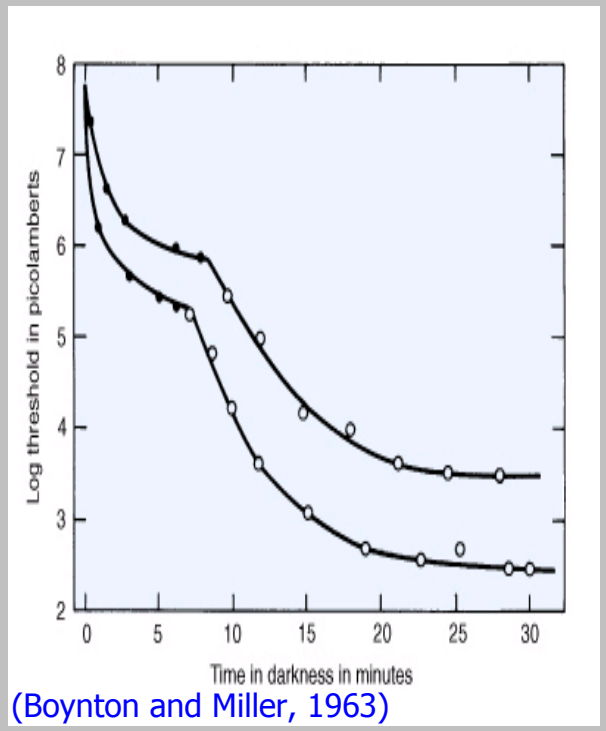
(De Boer, 1967)

$$W = 5 - 2\log\frac{E}{0.02\left(1+\sqrt{L/0.04}\right)\theta^{0.46}}$$

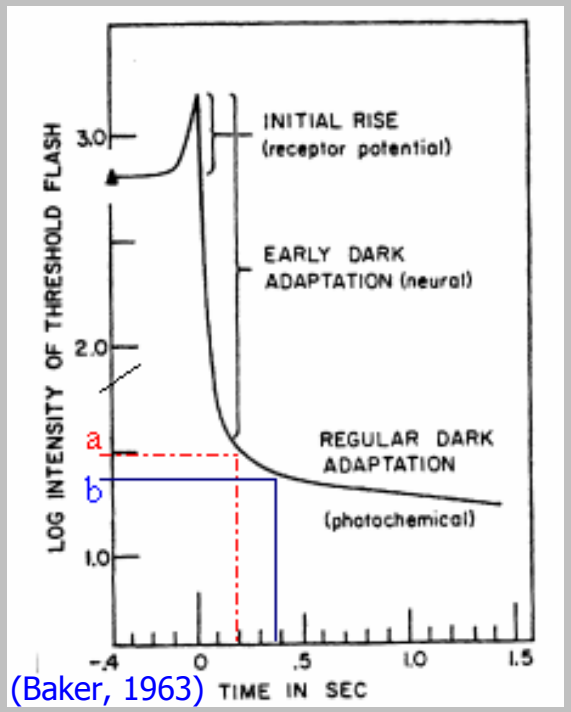
(Schmidt-Clausen and Bindels, 1974)

Recovery (Readaptation)

- Readaptation to lower light levels after glare exposure takes time
- Visual performance is reduced during this recovery period



(Boynton and Miller, 1963)



(Baker, 1963)

(See also Higgins and White, 1999; Lehnert, 2001; Schieber)

What do we know
Glare and visual performance

- Parameters that affect visual performance:
  (e.g., Mace et al., 2001)
  - Glare parameters:
    - **illuminance at the eye**
      (Schmidt-Clausen and Bindels, 1974; Flannagan et al., 1996; Bullough et al., 2003 and glare formulae)
    - **angle of the glare source**
      (Fry, 1954; Fu, 2001 and glare formulae)
    - **luminance/size**
      (Flannagan, 1999; Bullough et al., 2003)
    - **spectral power distribution**
      (Flannagan, 1999; Bullough et al., 2002, 2003)
    - **duration of exposure**
      (Fry, 1973)


Photo: www.surgicaleyes.org

What do we know
Glare and visual performance

- Parameters that affect visual performance:
  (e.g., Mace et al., 2001)
  - Environmental parameters:
    - **ambient conditions**
      (Andre and Owens, 1999; Akashi et al., 2003; Carlson and Urbanik, 2004)
    - **complexity/difficulty of location**
      (Theeuwes and Alferdinck, 1996; Bullough et al., 2003)
  - Observer parameters:
    - **age, visual health**
      (Campbell et al., 1998; Higgins and White, 1999; Schmitz et al., 2000; Peli, 2002; McGwin et al., 2003; Schieber)


Photo: www.surgicaleyes.org

Illuminance at the eye

- Increased glare illuminance results in increased veiling luminance, which decreases luminance contrast (Stiles, 1929)

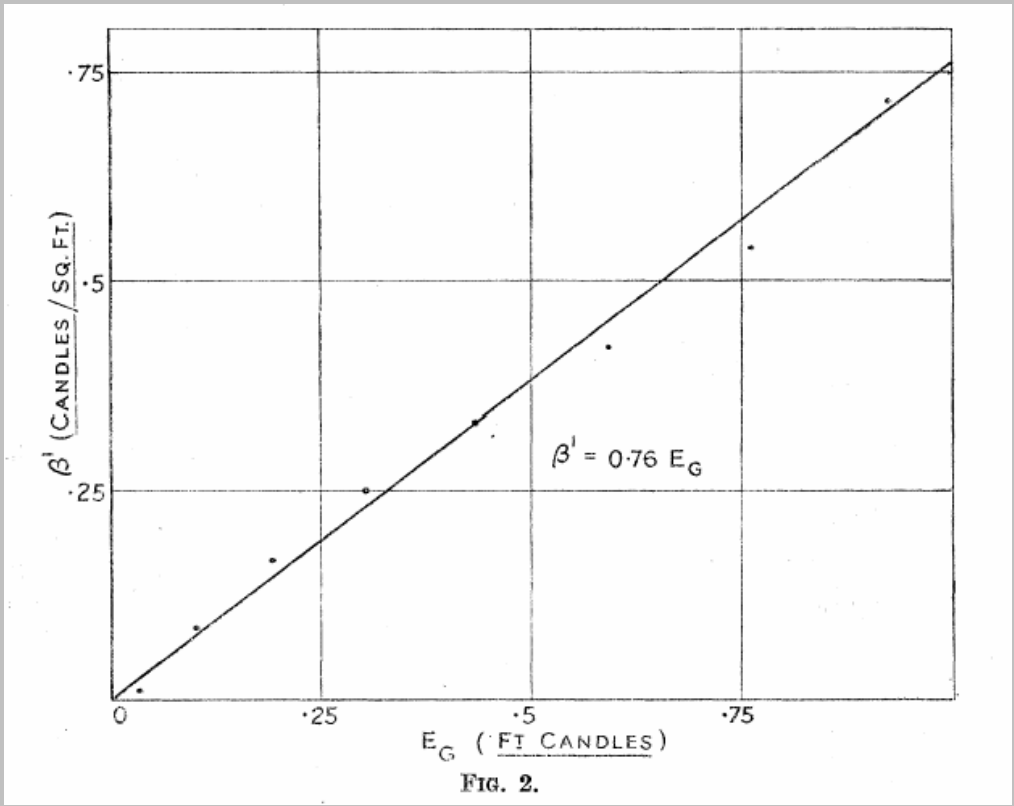


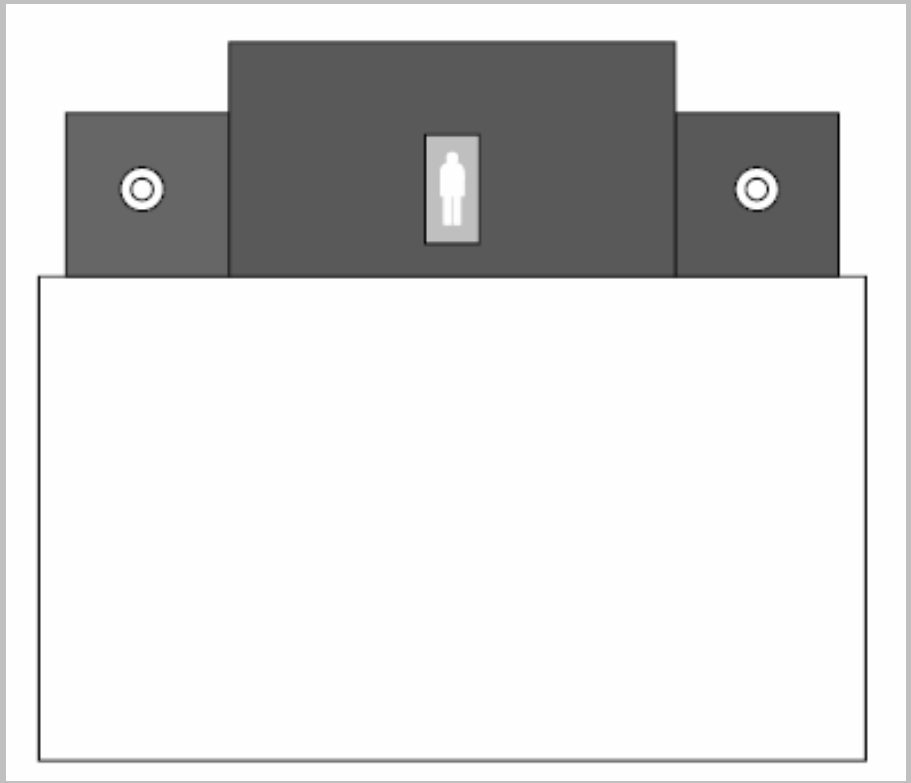
FIG. 2.

(Stiles, 1929)

(See also Flannagan et al., 1996; Flannagan, 1999; Ranney et al., 1999, 2000; Bullough et al., 2002, 2003 and existing glare formulae)

Luminance/size

- Size of glare source (0.3° or 0.6°) had no impact on detection of target (Flannagan, 1999)

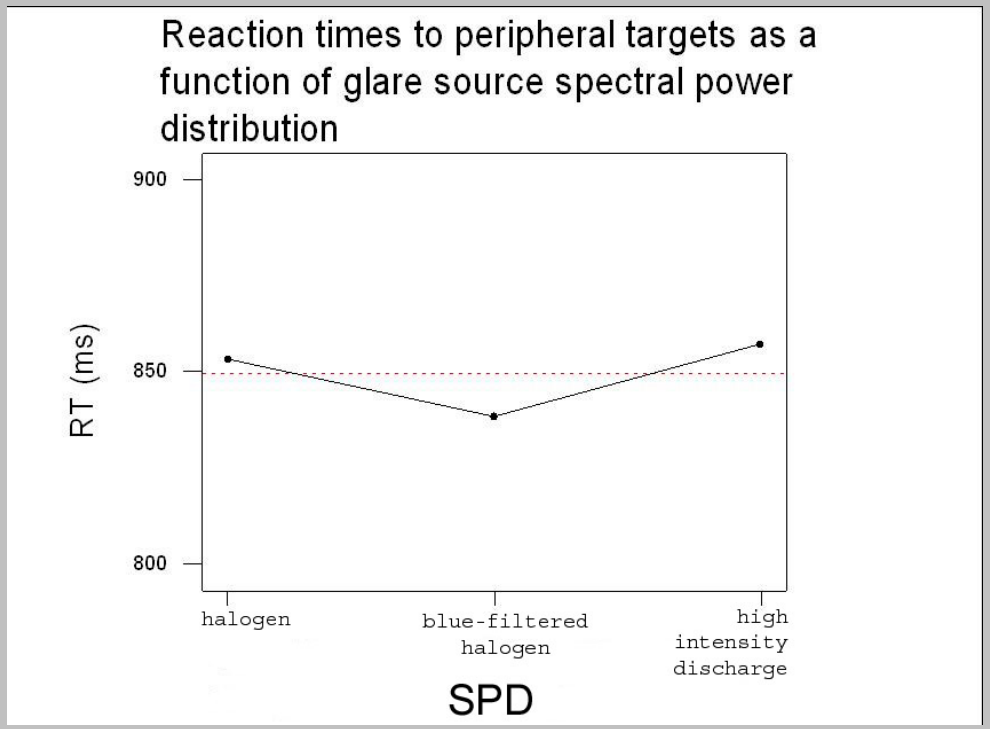


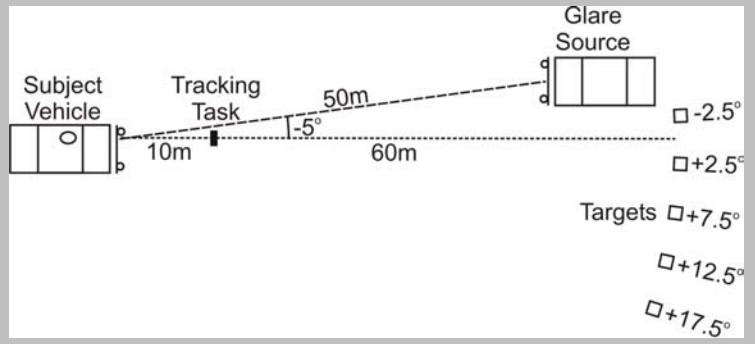
(Flannagan, 1999)

(See also Bullough et al., 2003; Van Derlofske et al., 2004)

Spectral power distribution

- Glare SPD has no impact on target detection (Bullough et al., 2003)



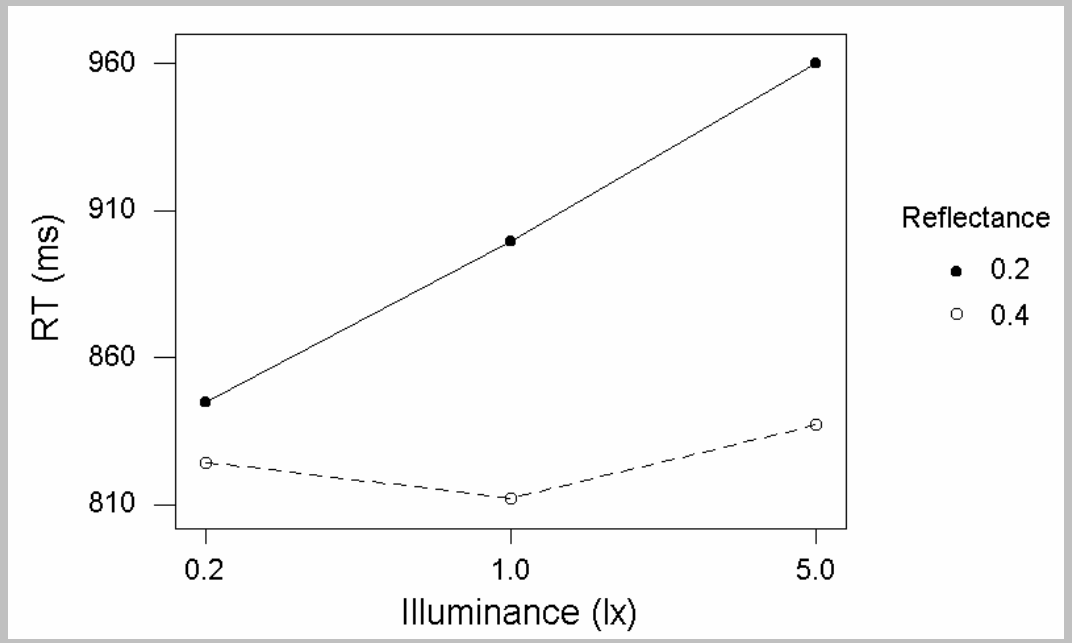


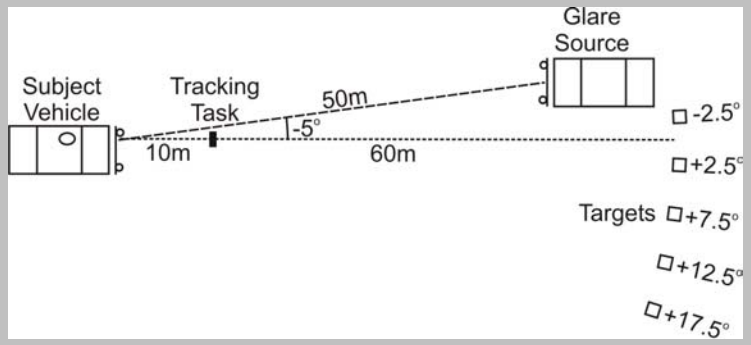
Bullough, 2003; NHTSA - DOT HS 809 672

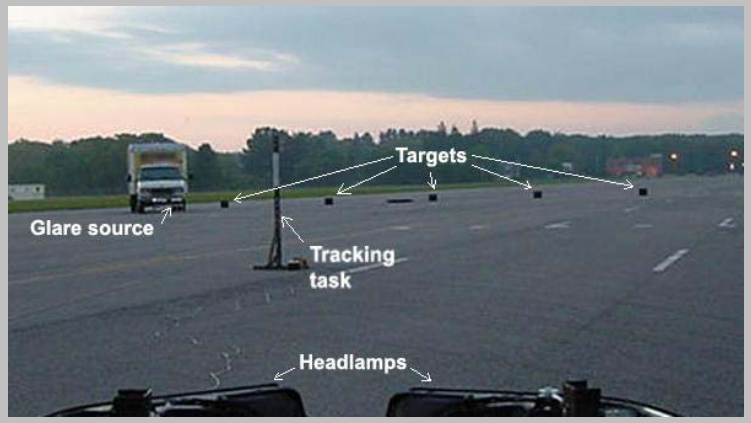
(See also Flannagan, 1999; Bullough et al., 2002, 2003)

Complexity/difficulty

- The impact of glare is larger for harder to see targets (Bullough, 2003)



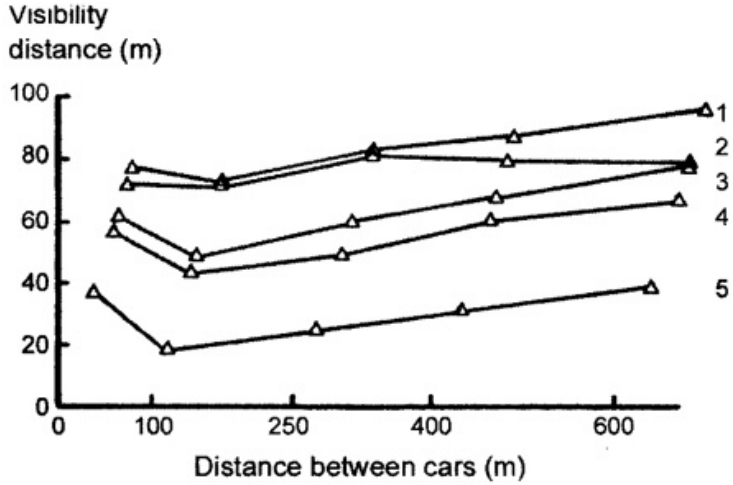




NHTSA - DOT HS 809 672

(See also Theeuwes and Alferdinck, 1996)

Ambient conditions



High beam luminous intensities (cd)

	Observer's car	Opposing car
1 -	260,000	220,000
2 -	low beam	low beam
3 -	130,000	220,000
4 -	87,000	220,000
5 -	29,000	220,000

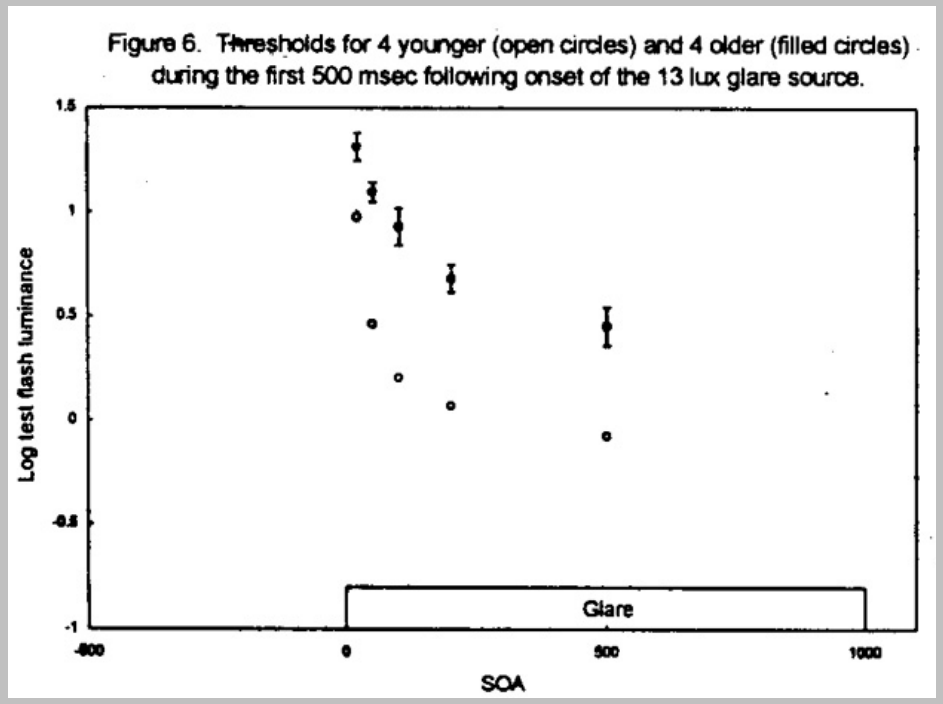
(Rumar, 1975)

- The impact of glare is less for higher ambient conditions (Rumar, 1975)

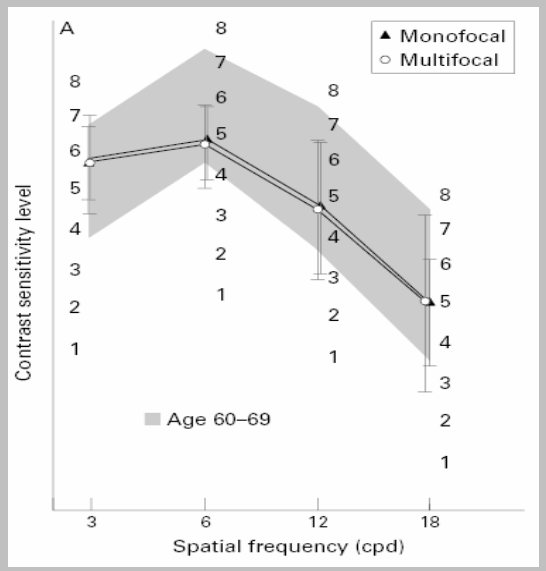
(See also Andre and Owens, 1999; Carlson and Urbanik, 2004)

Age/visual health

- Increased debris in older eyes results in increased scatter (Schmitz et al., 2000)
- Glare has a larger impact on visual performance for older subjects (Higgins and White, 1999)
- No difference in contrast threshold in presence of glare between groups of individuals with different types of intraocular lenses (Schmitz et al., 2000)



(Higgins and White, 1999)



(Schmitz et al., 2000)

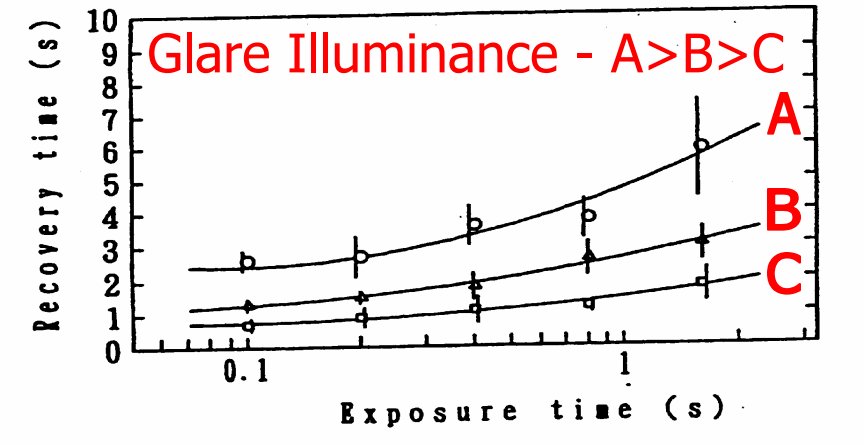
(See also Campbell et al., 1998; Higgins and White, 1999; Schmitz et al., 2000; Peli, 2002; McGwin et al., 2003; Schieber)

What do we know
Glare and visual recovery

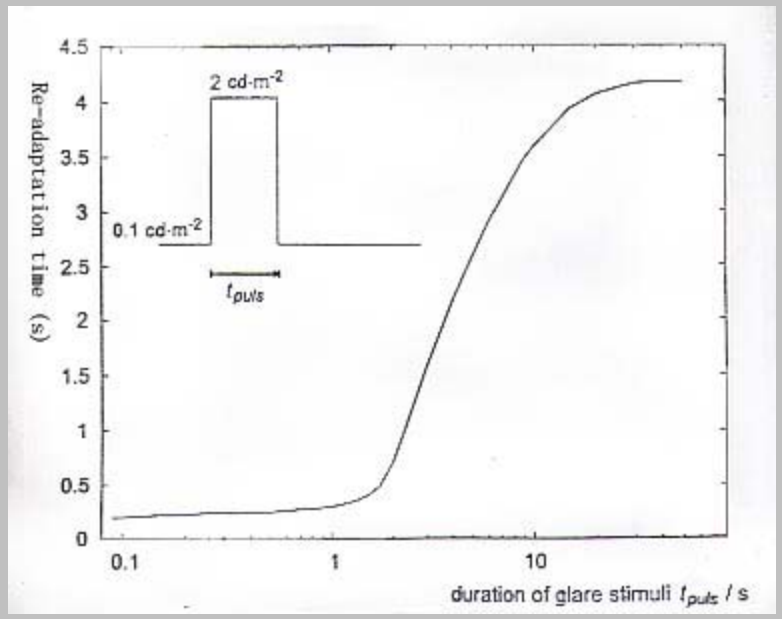
- Parameters that affect visual performance *after exposure*:
  - Glare parameters:
    - **illuminance at the eye** (Lehnert, 2001)
    - **duration of exposure** (Irikura et al., 1999)
    - **glare "dose"** (Chen, 2004; Irikura et al., 1999)
  - Environmental parameters:
    - **ambient lighting** (Irikura et al., 1999)
  - Observer parameters:
    - **age, visual health** (Higgins and White, 1999; Kamppeter et al., 2003; Schieber)

Glare Illuminance and Exposure Time

- Increased glare illuminance increases recovery time (Irikura et al., 1999)
- Increased glare exposure time increases recovery time (Lehnert, 2001)



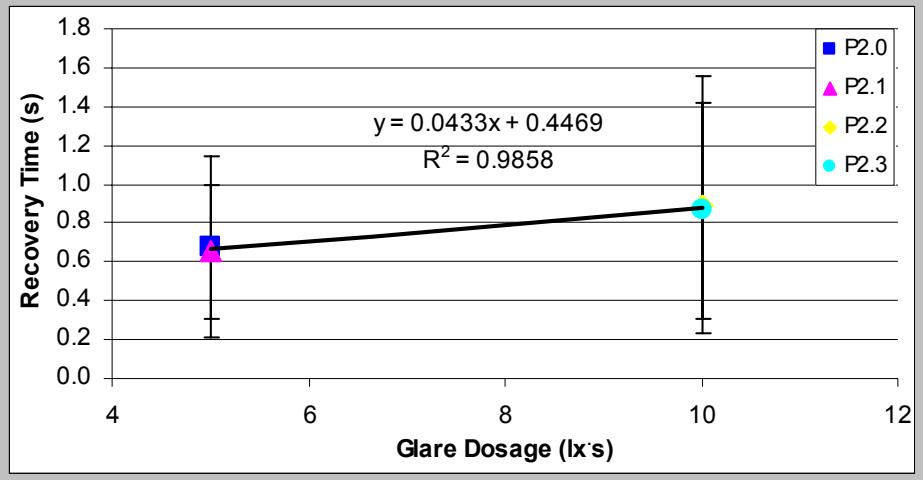
(Irikura et al., 1999)



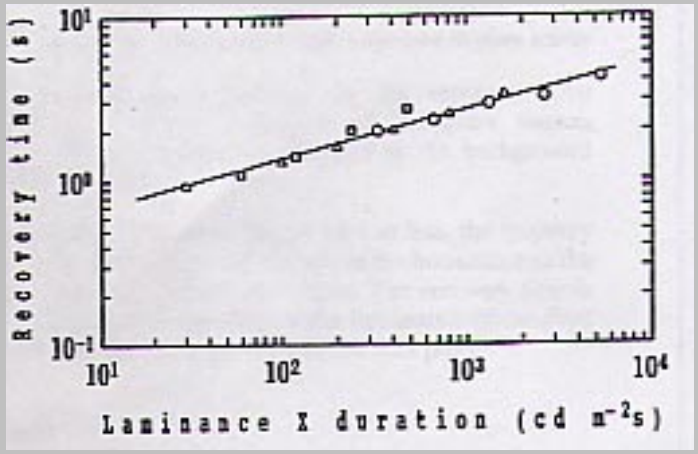
(Lehnert, 2001)

Glare Dosage

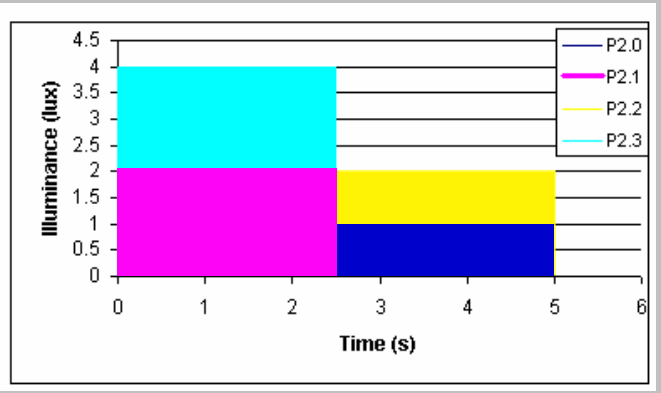
- Recovery time increases with increasing glare dosage (veiling luminance * duration) (Chen, 2004; Irikura et al., 1999)



Chen (2004)



Irikura et al (1999)

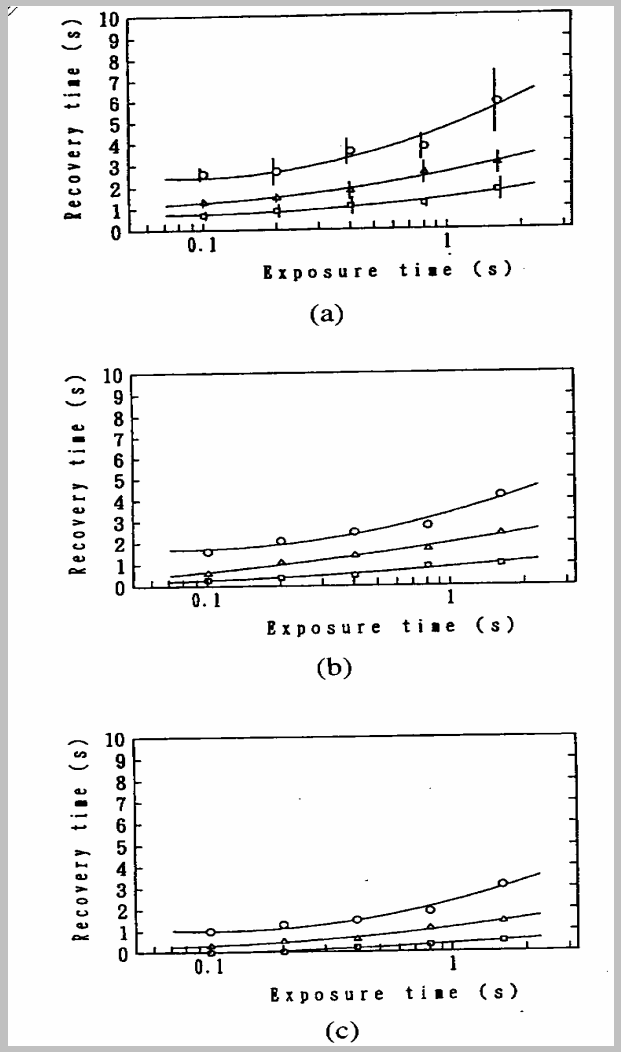


Chen (2004)

Ambient Lighting

- Recovery time decreases with increasing ambient lighting (Irikura et al., 1999)

Ambient Lighting



(Irikura et al., 1999)

Age/visual health

- Older observers took longer to recover from glare (Schieber)
- Recovery times after glare exposure were longer in glaucoma patients than in normally-sighted individuals (Kamppeter et al., 2003)

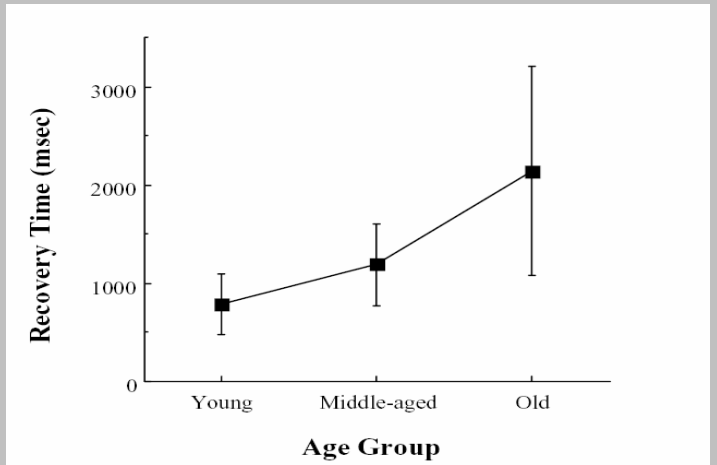
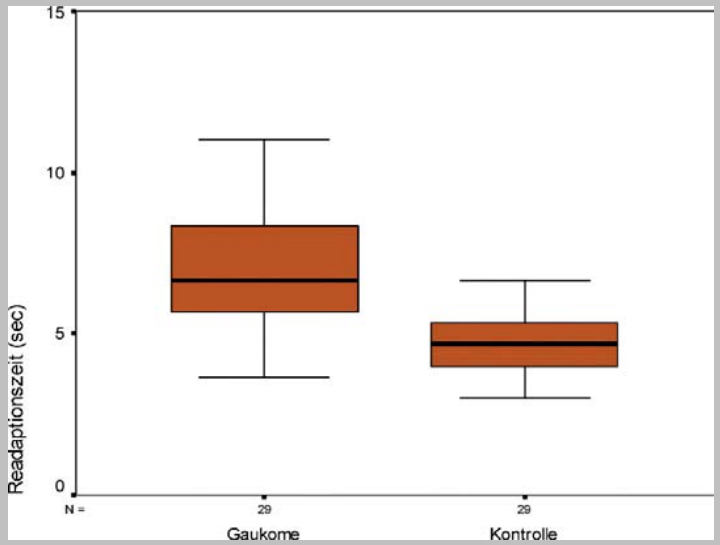


Figure 2. Glare recovery time as a function of age.



(See also Schieber; Kamppeter et al., 2003); Higgins and White, 1999)

What do we know
Glare and visual comfort?

- Several parameters affect visual comfort:
  - Glare parameters:
    - **illuminance at the eye**

      (Schmidt-Clausen and Bindels, 1974; Bhise et al., 1977; Olson and Sivak, 1984; Flannagan et al., 1992, 1993; Bullough et al., 2002, 2003)

    - **luminance**

      (Sivak et al., 1990; Alferdinck and Varkevisser, 1991; Flannagan, 1999; Manz, 2001; Völker, 1999; Bullough et al., 2002, 2003; Van Derlofske, 2003, 2004)

    - **spectral power distribution**

      (Flannagan et al., 1989, 1992, 1993; Flannagan, 1999; Bullough et al., 2002, 2003; Van Derlofske, 2003, 2004)

    - **duration**

      (Sivak et al., 1999; Lehnert, 2001)

What do we know
Glare and visual comfort?

- Several parameters affect visual comfort:
  - Environmental parameters:
    - **ambient lighting**

      (Schreuder, 1969; Schmidt-Clausen and Bindels, 1974; Bullough et al., 2002)
    - **complexity/difficulty of location**

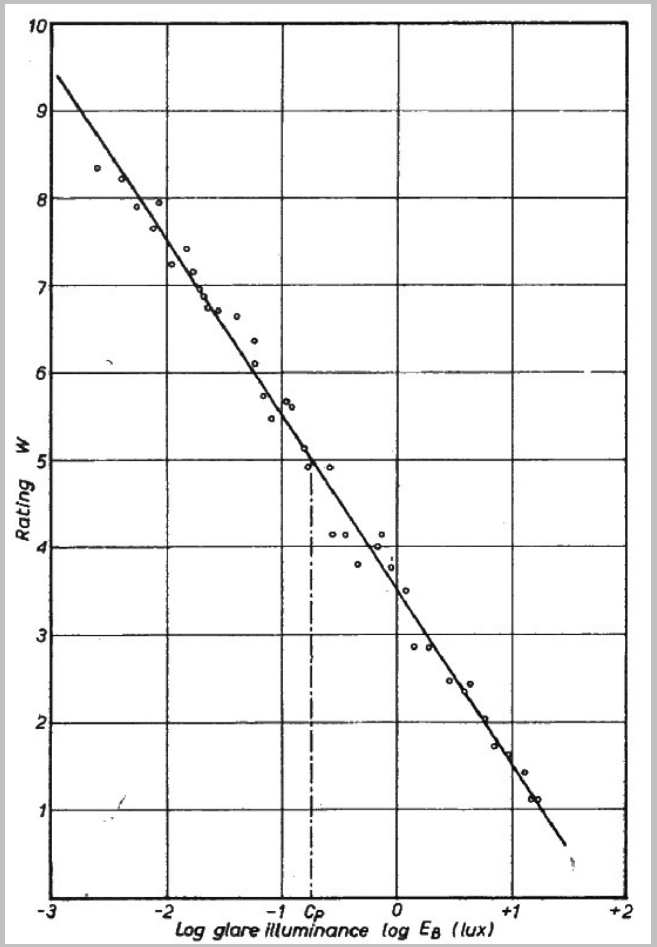
      (Sivak et al., 1991; Bullough et al., 2003)
  - Observer parameters:
    - **experience and expectations**

      (Sivak et al., 1989)
    - **age/visual health**

      (Tsongos and Schwab, 1970; Flannagan et al., 1993; Olson and Sivak, 1984; Theeuwes and Alferdinck, 1996; Sivak et al., 1999)

Illuminance at the eye

- Increased glare illuminance at the eye results in increased discomfort (Schmidt-Clausen and Bindels, 1974)

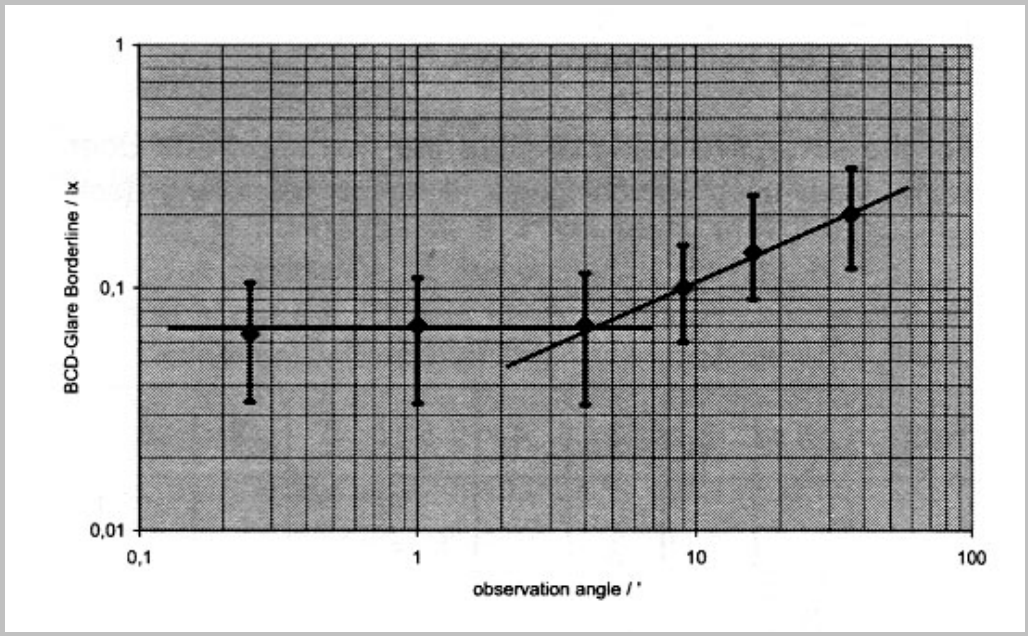


(Schmidt-Clausen and Bindels, 1974)

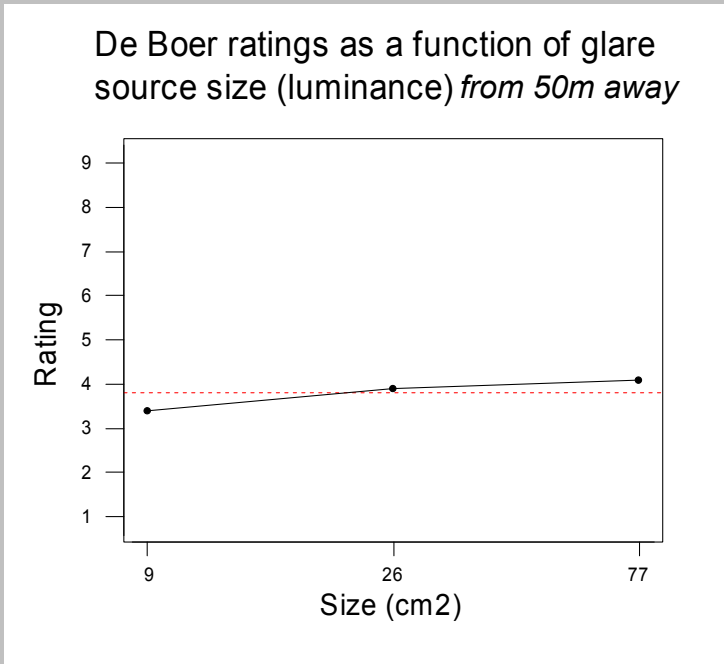
(See also Bhise et al., 1977; Bullough 2002, 2003; Olson and Sivak, 1984; Flannagan et al., 1992, 1993, Van Derlofske et al., 2003, 2004)

Luminance/Size

- Increased glare luminance (smaller source size) results in increased discomfort, *up to some limit* (Rosenhahn and Lampen, 2004; Bullough, 2003)



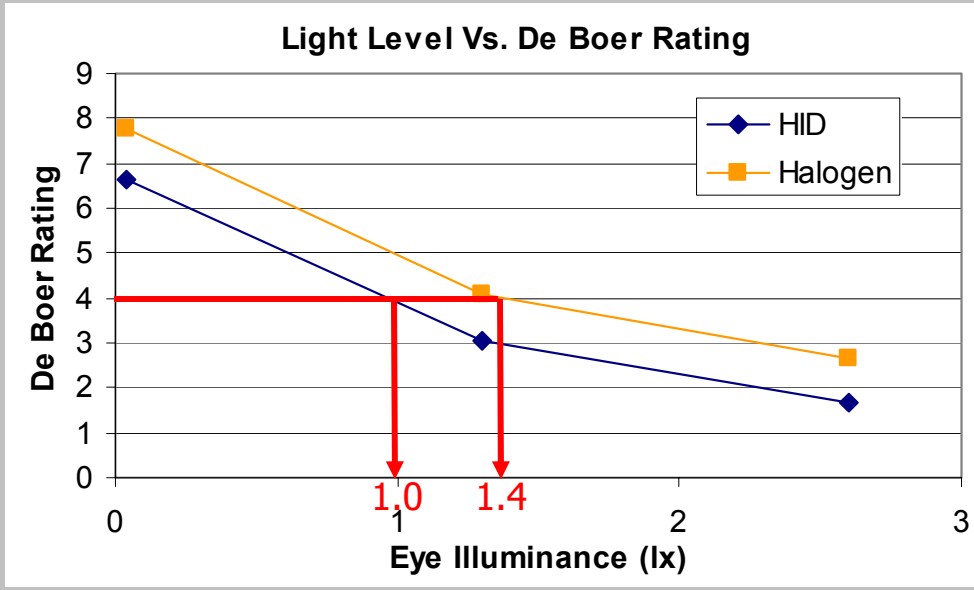
Rosenhahn and Lampen (2004)



Bullough, 2003: NHTSA - DOT HS 809 672

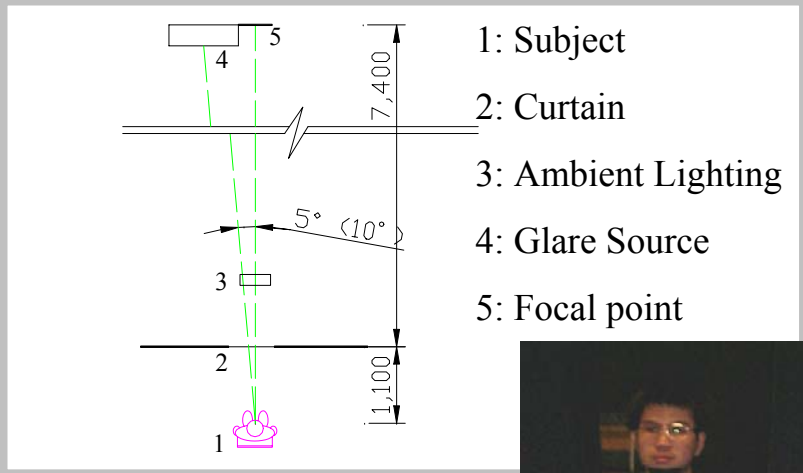
(See also Sivak et al., 1990; Alferdinck and Varkevisser, 1991; Bullough, 2003; Flannagan, 1999; Manz, 2001; Van Derlofske et al., 2004; Völker, 1999)

Spectral power distribution



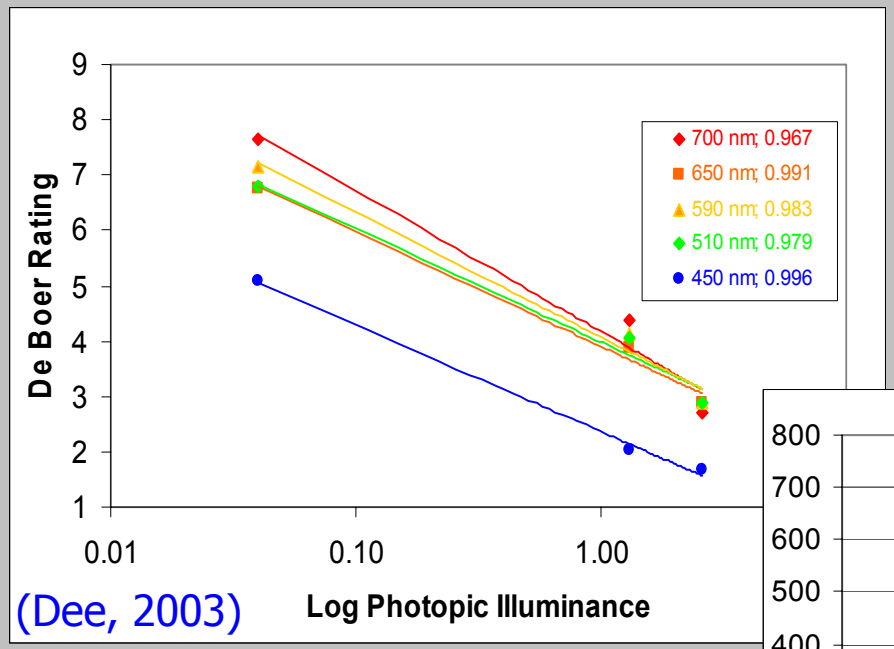
~40% more halogen light is need vs. HID to result in a De Boer rating of 4

- For the same illuminance, glare light with more short wavelength energy will cause more discomfort (Fu, 2002)



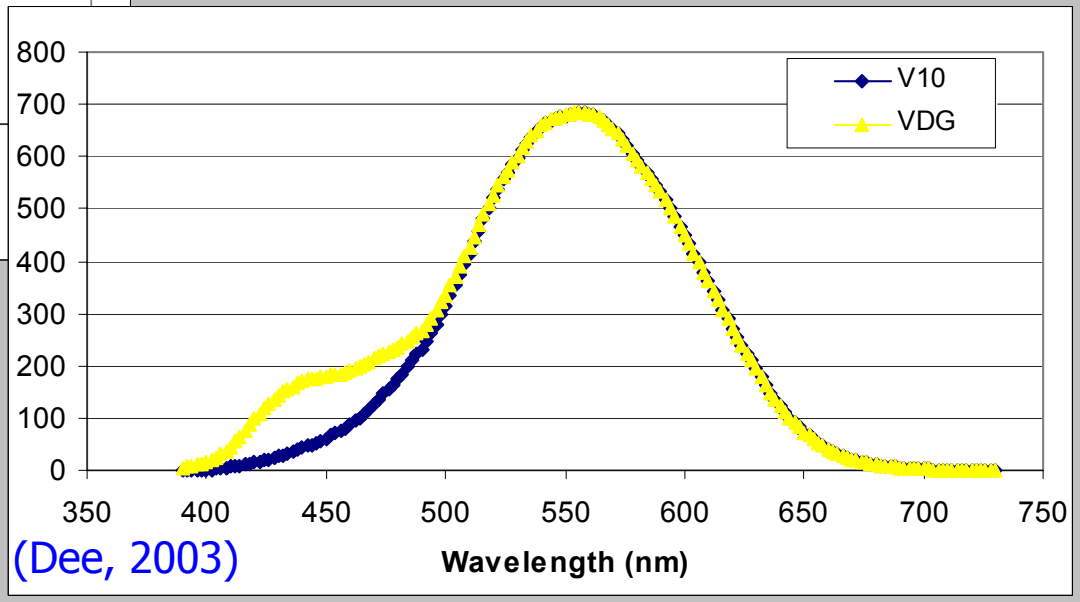
(See also Flannagan et al., 1989; Flannagan, 1999; Bullough et al., 2002)

Spectral power distribution



(Dee, 2003)

- Evidence suggests short wavelength cone photoreceptors may play an increased role in the sensation of discomfort (Dee, 2003)

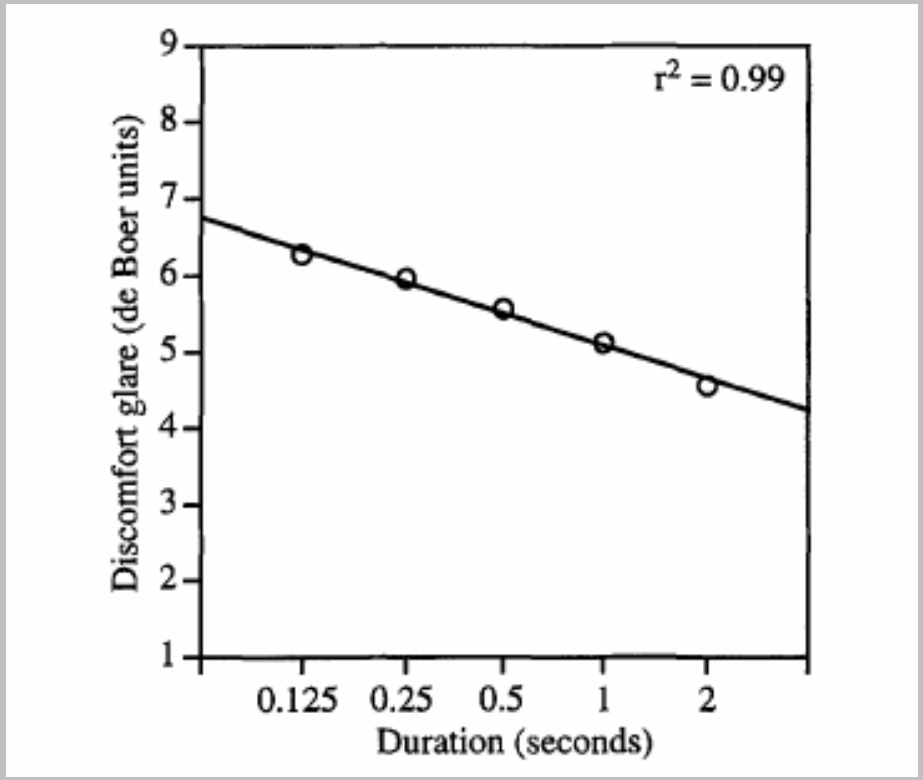


(Dee, 2003)

(See also Flannagan et al., 1989; Flannagan, 1999; Bullough et al., 2002)

Duration

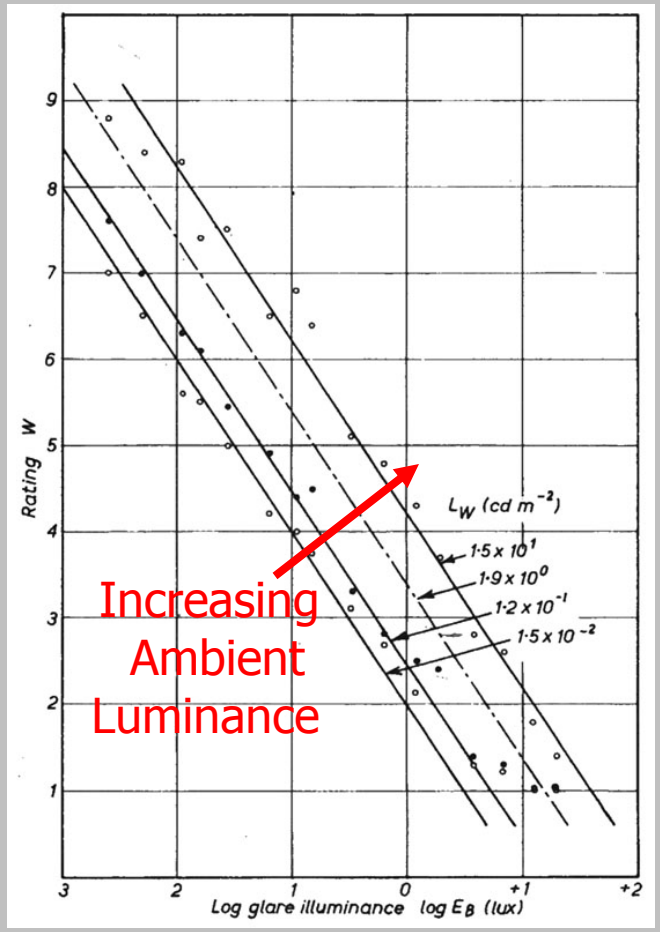
- Longer exposure to glare results in increased discomfort (Sivak et al., 1999)



(see also Chen 2004; Lehnert, 2001)

Ambient lighting

- Increased ambient lighting results in decreased discomfort from glare (Schmidt-Clausen and Bindels, 1974)

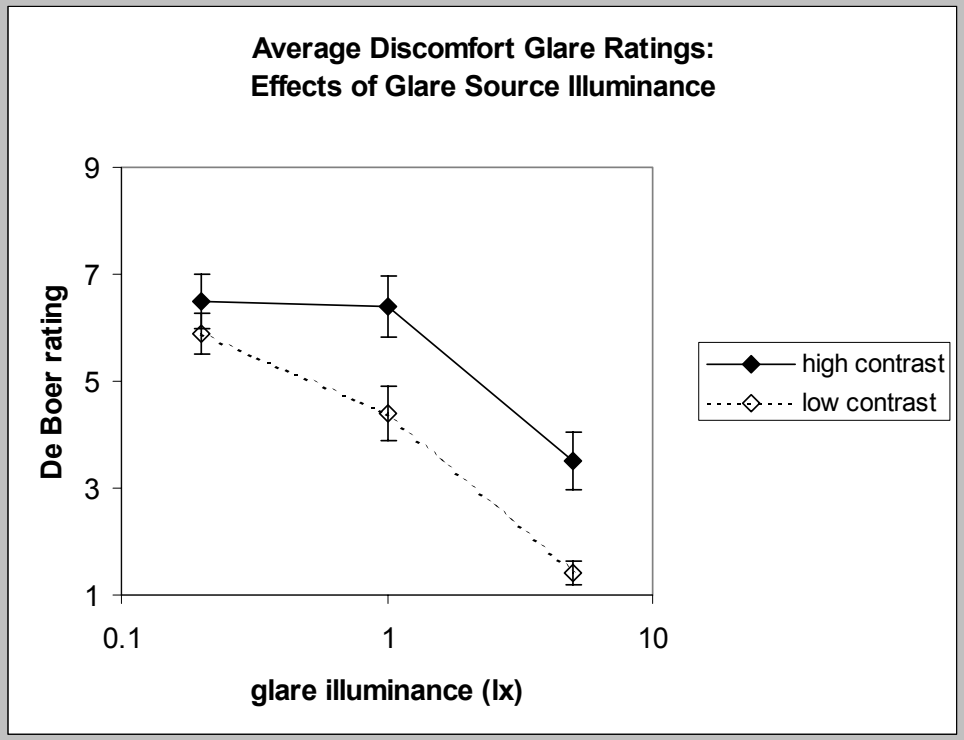


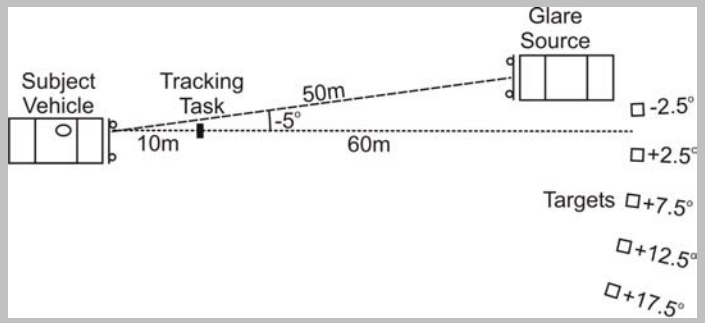
Schmidt-Clausen and Bindels, 1974

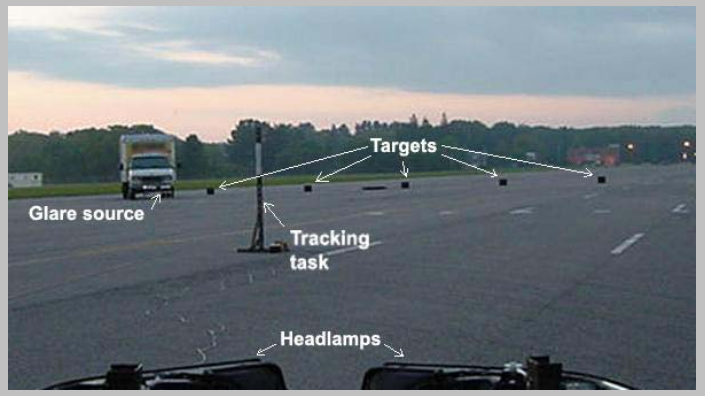
(Also see Schreuder, 1969; Bullough et al., 2003)

Complexity/Difficulty

- Difficult visual tasks increase feelings of discomfort from glare (Bullough et al., 2003)



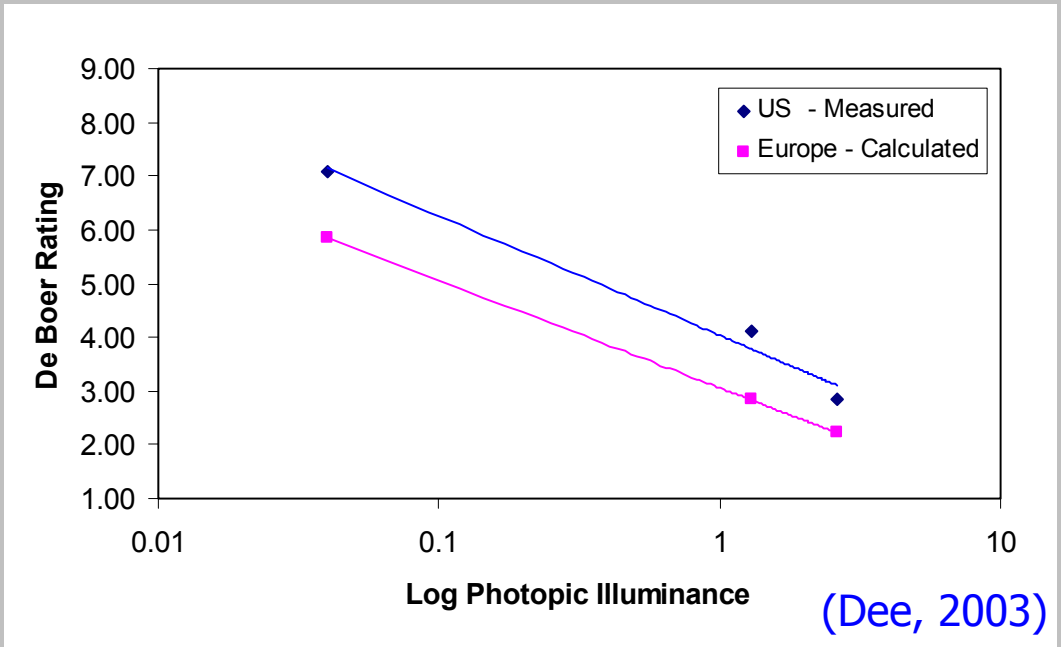




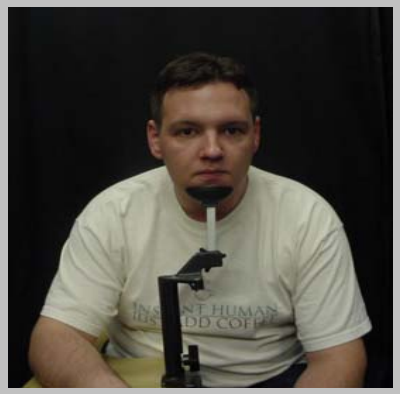
Bullough, 2003: NHTSA - DOT HS 809 672

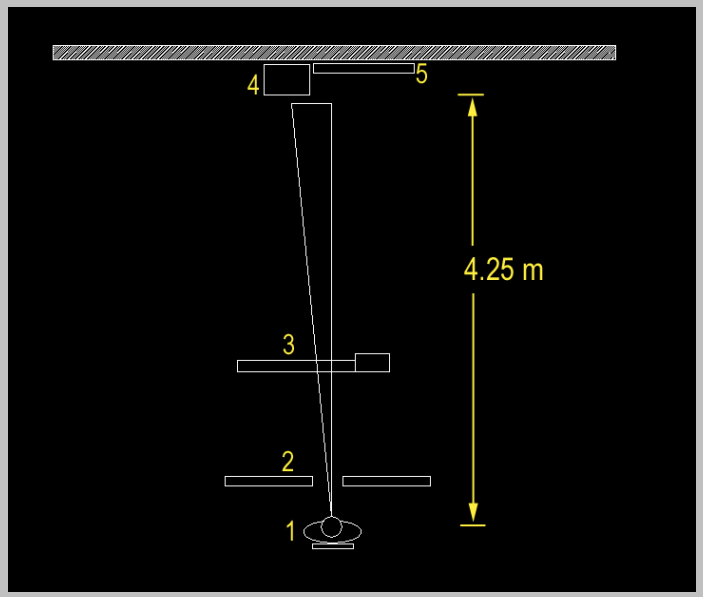
(see also Sivak et al., 1991;
Van Derlofske et al., 2003, 2004)

Experience/expectations



(Dee, 2003)

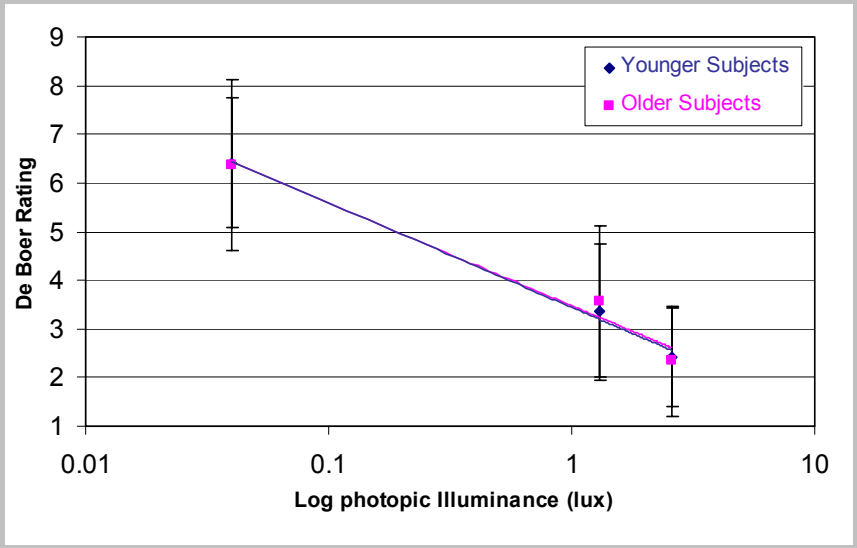




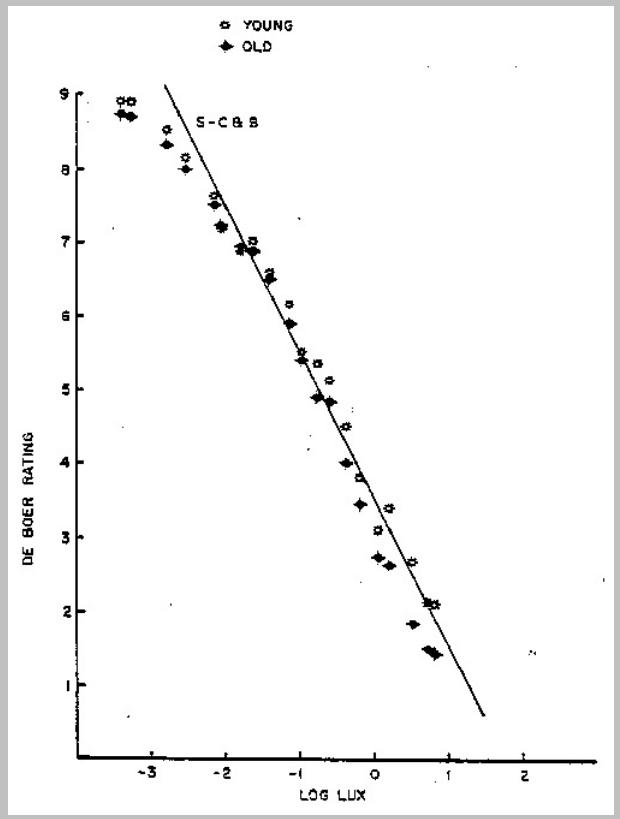
- Ratings in North America reported to be 1 to 2 De Boer ratings higher than that in Europe (*Sivak et al., 1989)*

Age/Visual Health

- Age may have a small impact on feelings of discomfort from glare (Olson and Sivak, 1984; Dee, 2003)



(Dee, 2003)



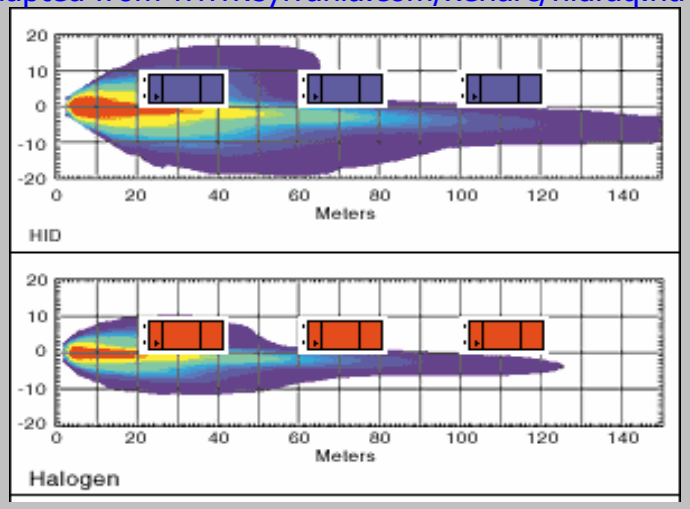
(Olson and Sivak, 1984)

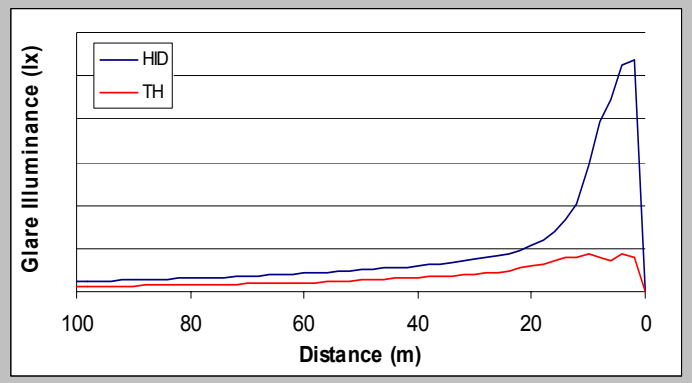
(Research shows contradictions: see also Tsongos and Schwab, 1970; Flannagan et al., 1993; Theeuwes and Alferdinck, 1996; Sivak et al., 1999; Dee, 2003)

Addressing These Issues

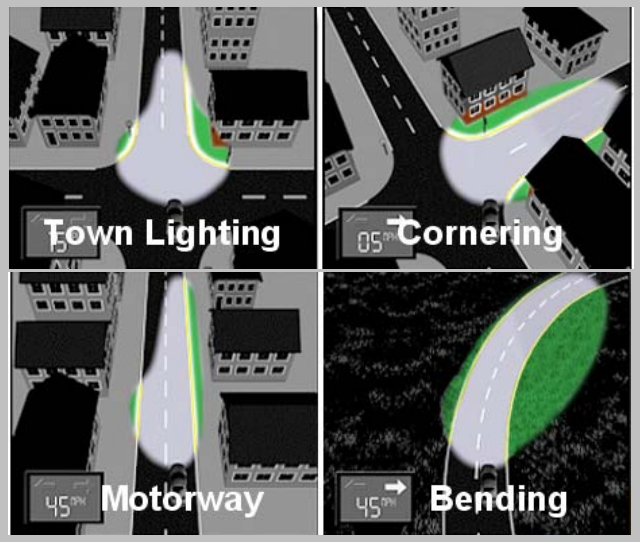
- Using new source technologies, system technologies, and optical design strategies
  - Beam Photometry
    - New distributions
    - Active distributions
      (advanced front lighting systems - AFS)

(Adapted from www.sylvania.com/xenarc/hidfaq.htrr)





(Chen, 2004)



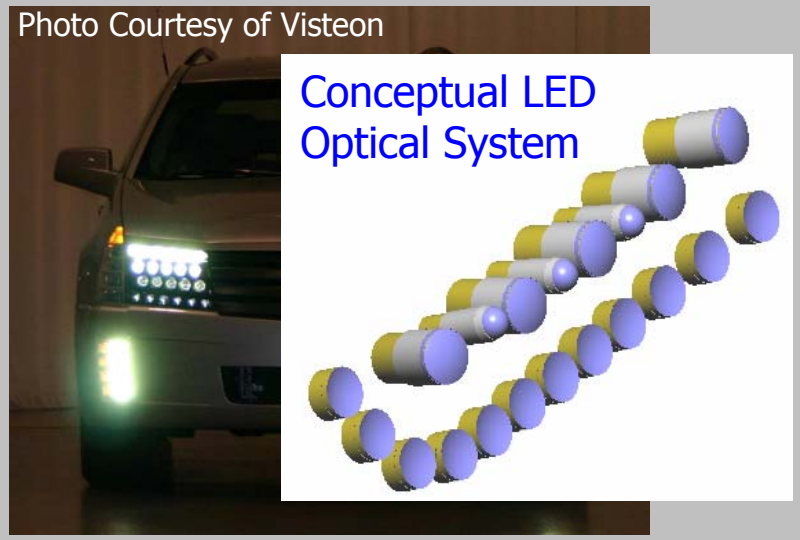
(visteon.wieck.com/image_database)

Lighting Research Center

Rensselaer

Addressing These Issues

- Using new source technologies, system technologies, and optical design strategies
  - Headlamp luminance/size
    - Multi source systems can distribute luminance



(Van Derlofske, 2004)

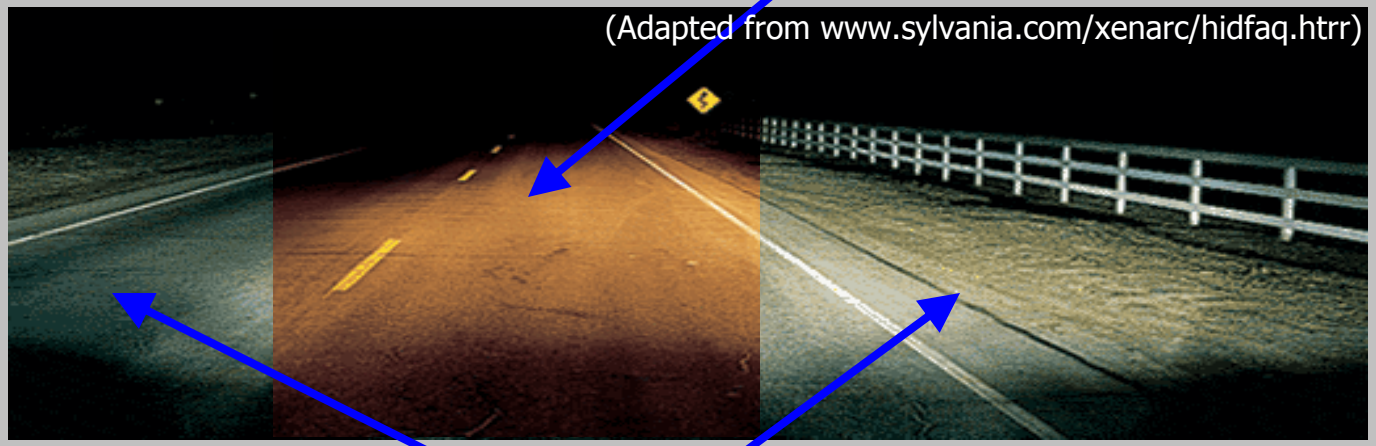
Source	Flux	Luminance
LED Current	30 - 80 lm	4 - 10 cd/mm^2
LED Projected*	375 lm	~ 24 cd/mm^2
Halogen	1500 lm	~ 25 cd/mm^2

*Kern, 2004

Addressing These Issues

- Using new source technologies, system technologies, and optical design strategies
  - Beam spectrum
    - New spectral distributions
    - Increase visibility, decrease glare

Decreased short wavelength content
to decrease discomfort



Increased short wavelength content
to increase visual performance

Conclusions

- Much is known about glare and ***visual performance*** and ***discomfort***
- However, Metrics *are* lacking
  - Relatively little is known about how glare affects ***driving behavior*** (Aktan and Schnell, 2003) and ***safety***
    - NHTSA and the LRC are performing a 100-car naturalistic study to start to answer these questions