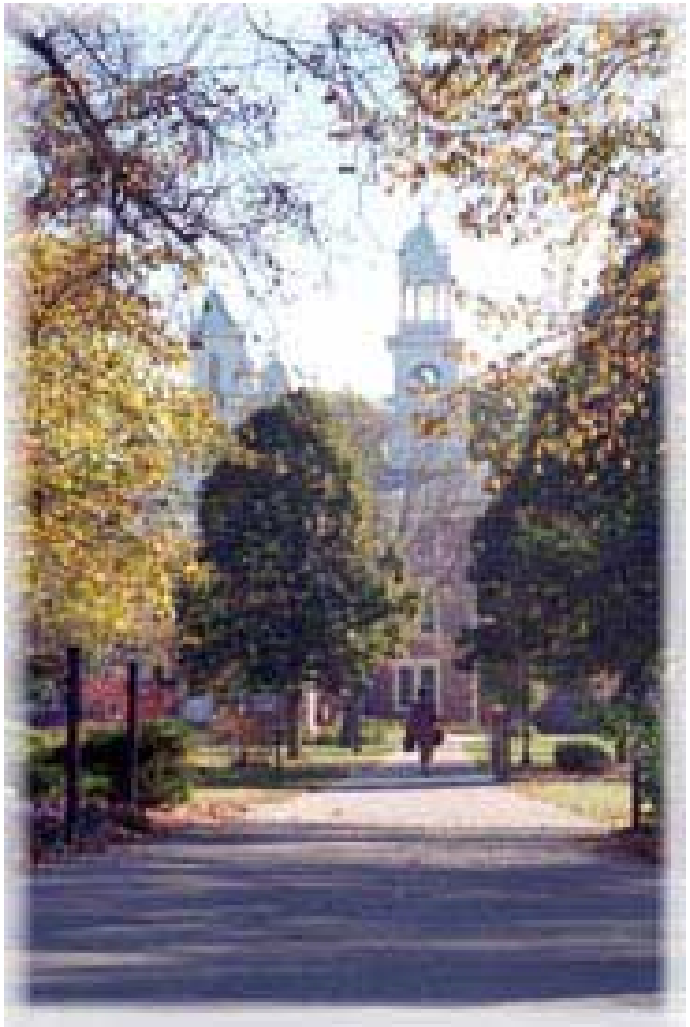


Fluorescent Colors & Human Performance: Models, Mechanisms and Experimental Data

Frank Schieber
Professor of Psychology
April/October 2006

Heimstra Laboratories
University of South Dakota

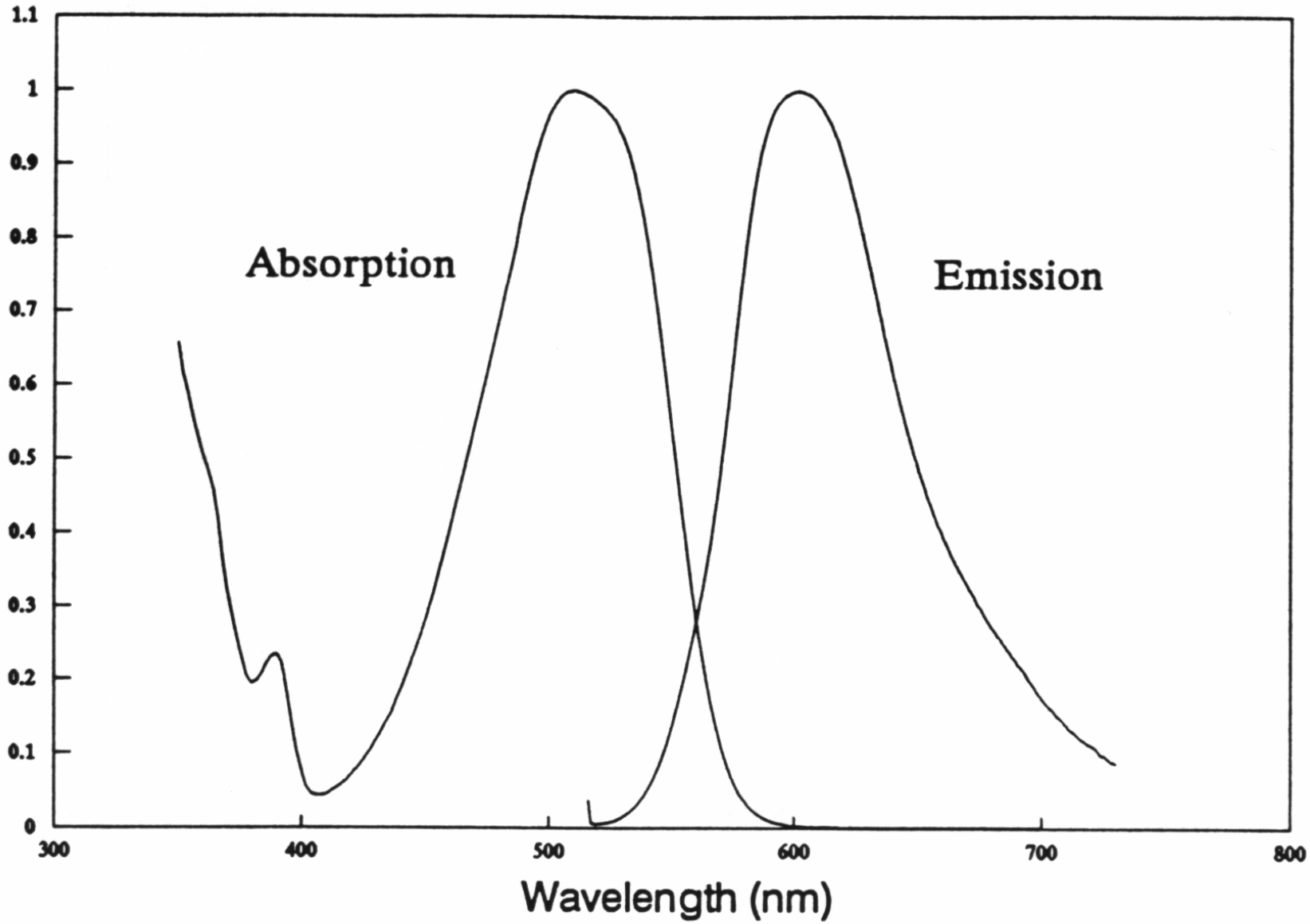
Fluorescent Highway Signs

- The Phenomenon of Fluorescence
- Daytime Visibility Benefits for Traffic Control Devices
- Photometric Properties related to the Apparent Luminosity of Fluorescent Materials
- A Laboratory Evaluation of the Attention Grabbing Capacity of Fluorescent Colors

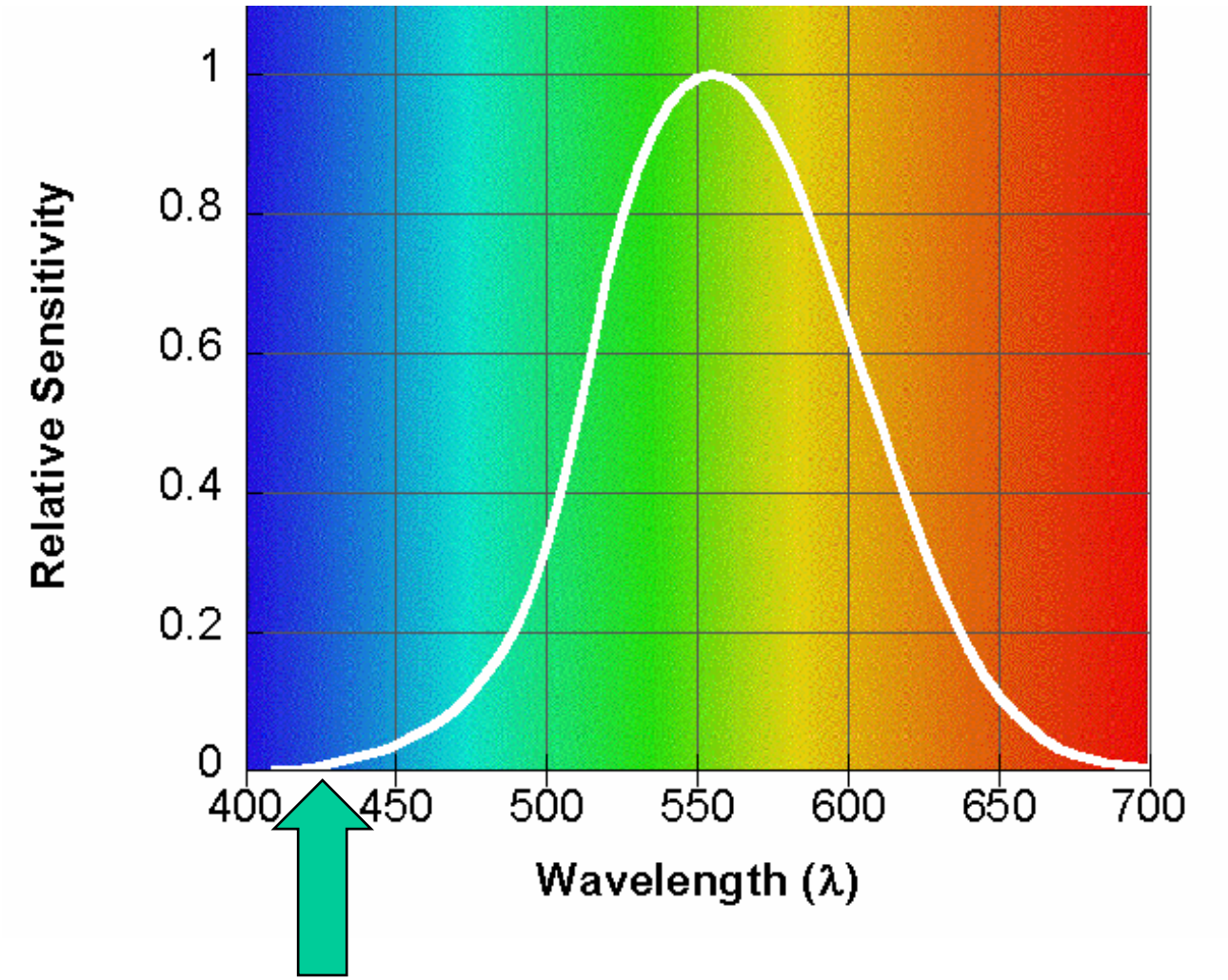
What is fluorescence?

Absorption of short-λ light that is subsequently re-emitted as longer-λ light

Typical "Stokes Shift" for Organic Fluorescent Material

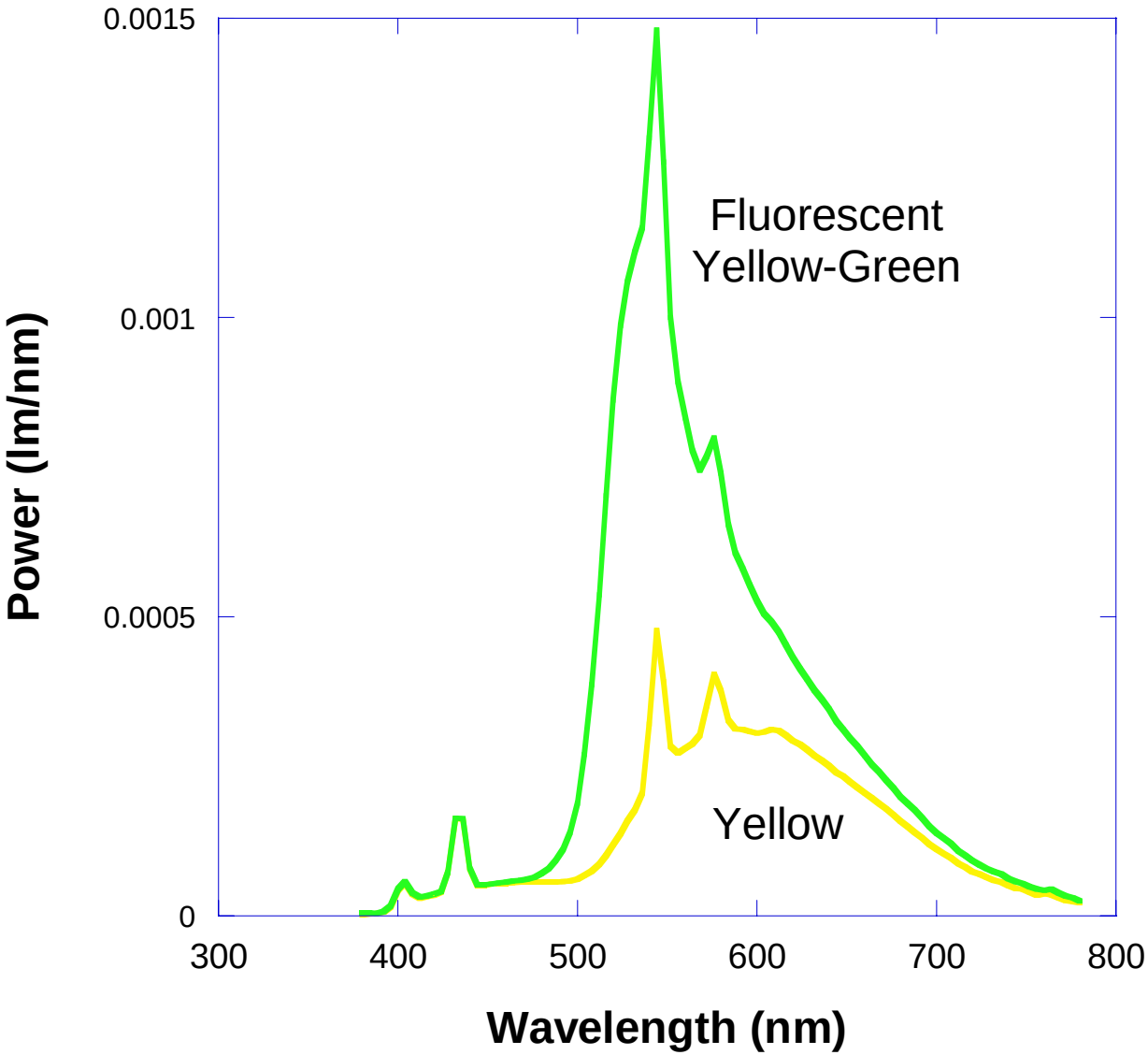


Human Visibility Function (V_λ)



Absorption λ for durable fluorescent signs

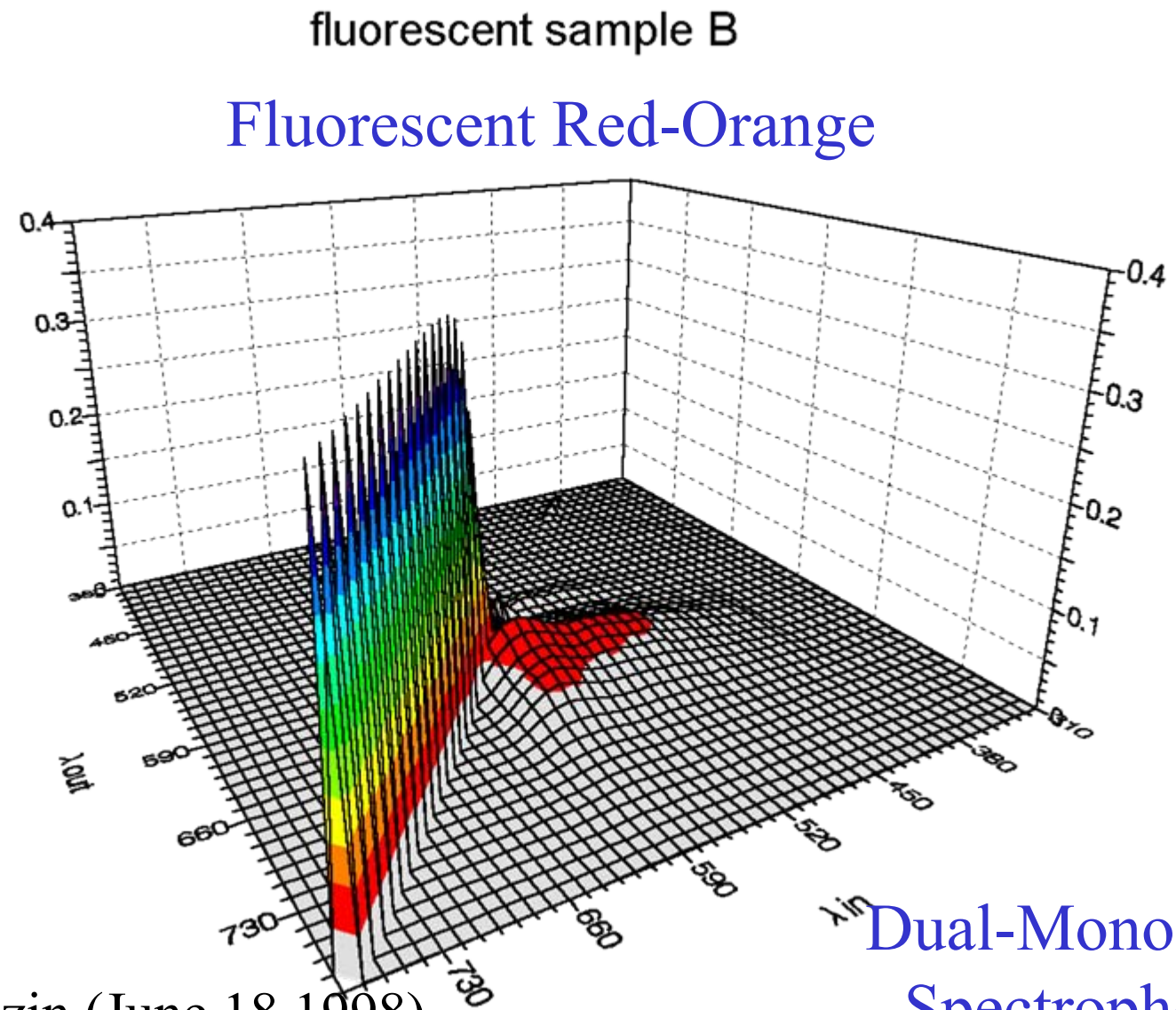
Spectral Density Distributions: Yellow vs. Fluorescent-YG



Source:
3M Sheeting

USD Solar Simulator

Bispectral Reflectance Distribution

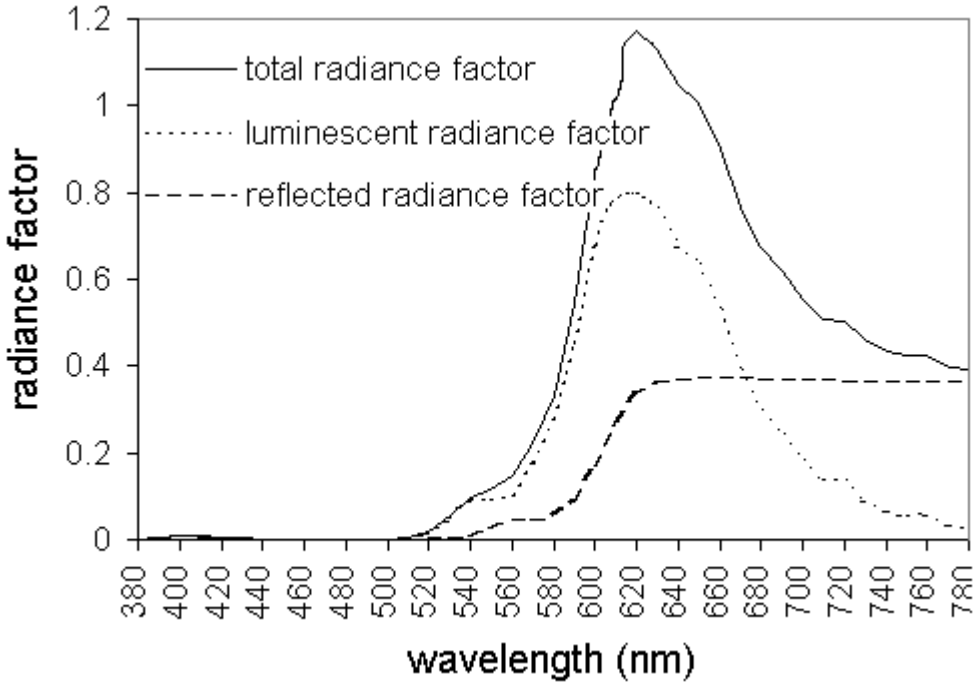


Fluorescent Red-Orange

Dual-Monochromator Spectrophotometer

D.Couzin (June 18,1998)

Spectral Power Distribution
Fluorescent Red-Orange



$Y_{total} = Y_r + Y_f$

$Y_r = 7.3$

$Y_f = 23.2$

$Y_{total} = 30.5$

Benefits
of
Fluorescent Highway Signs

Jennsen, et al. (1997)
Flourescent: Yellow and Yellow-Green

- Fluorescent signs detected and recognized at greater distances
- Recognition advantage:
  young drivers: 57 m (2.1 s @ 100 k/m)
  old drivers: 90 m (3.2 s @ 100 k/m)
- Eye movement field study:
  Fluorescent signs first fixated at greater distances and less likely to be skipped

Zwahlen & Schnell (1997)
Peripheral Field Conspicuity

- briefly presented signs of varying size, color and eccentricity
- fluorescent signs detected and recognized at greater distances than their non-fluorescent counterpart

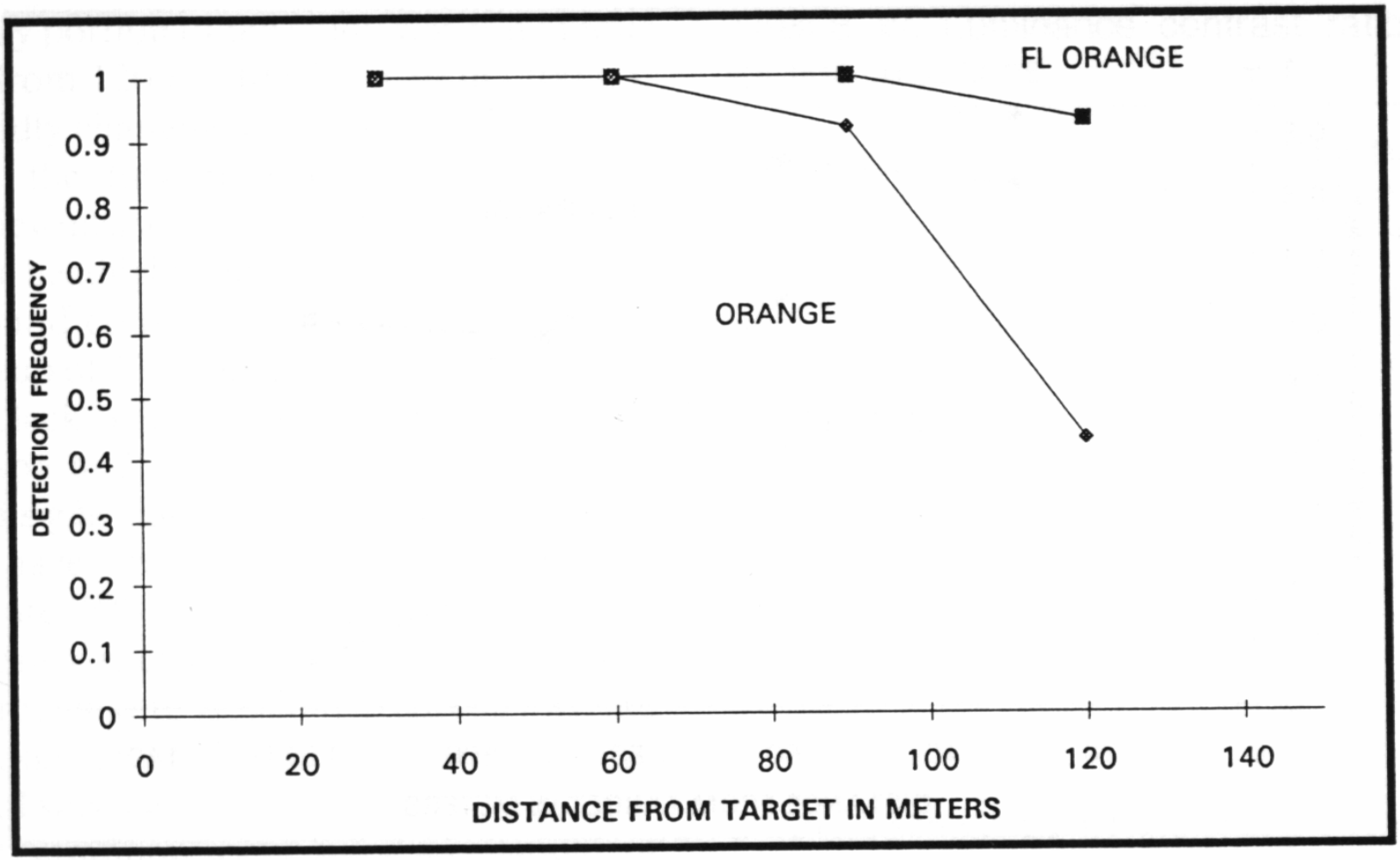
Hummer & Scheffler (1999) Workzone Driver Behavior

- Fluorescent Orange versus Non-Fl. Orange ("Left Lane Closed Ahead")
- (4) Treatment and (3) Control sites
- 5 month Observation Period
- Drivers vacated left lane sooner in workzones with Fluorescent Orange Signs
- Traffic Conflicts (n.s.)

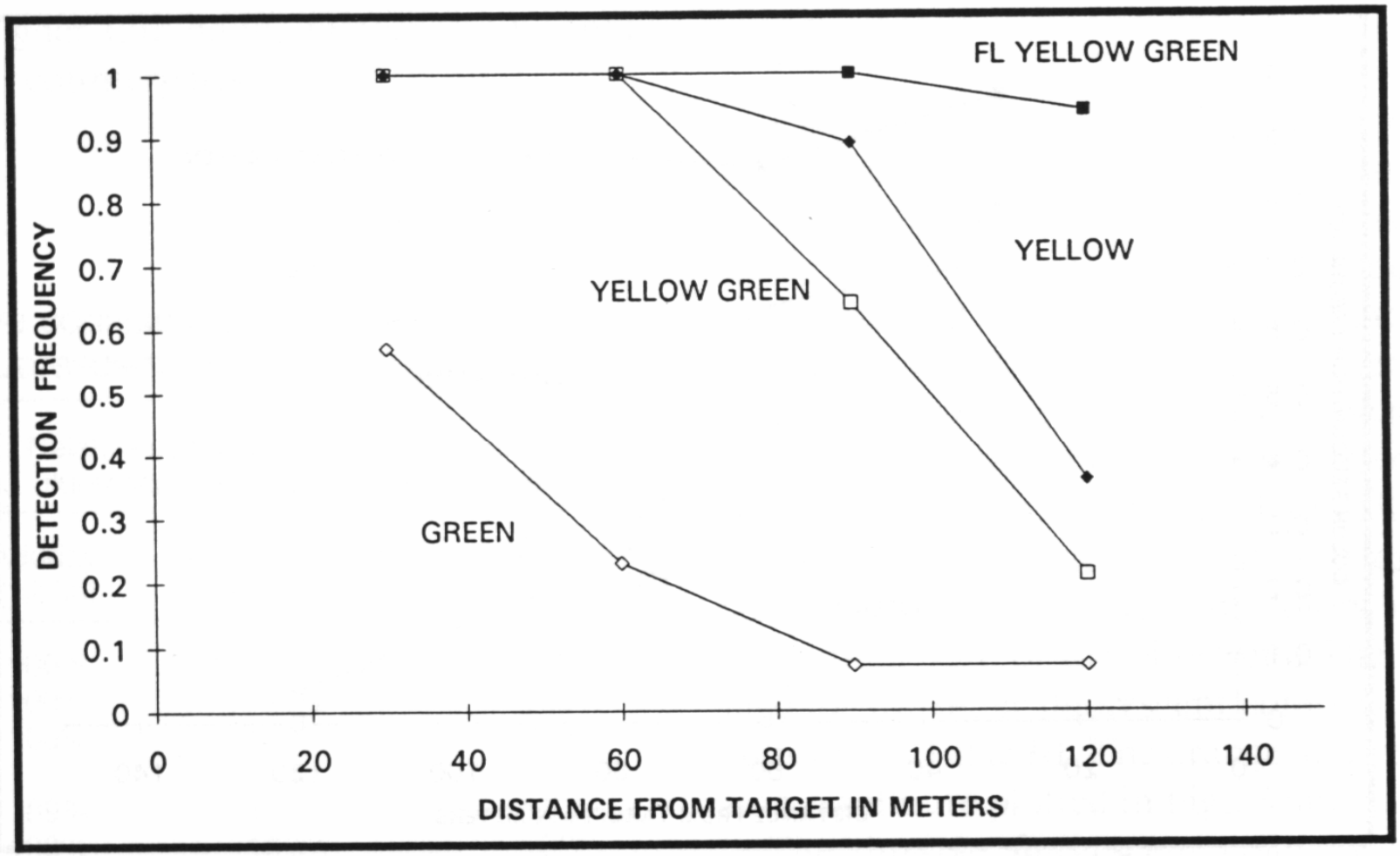
Burns & Pavelka (1995)
Subjective Appearance/Evaluation

- Orange, Red, Yellow, Yellow-Green, (Green)
- Pair-wise comparisons of disk targets against "camouflaged" background
- Visibility (Can you see either target?)
  Recognition (What color are the targets?)
  Relative Conspicuity (Which is more noticable?)
- Fluorescent signs consistently superior

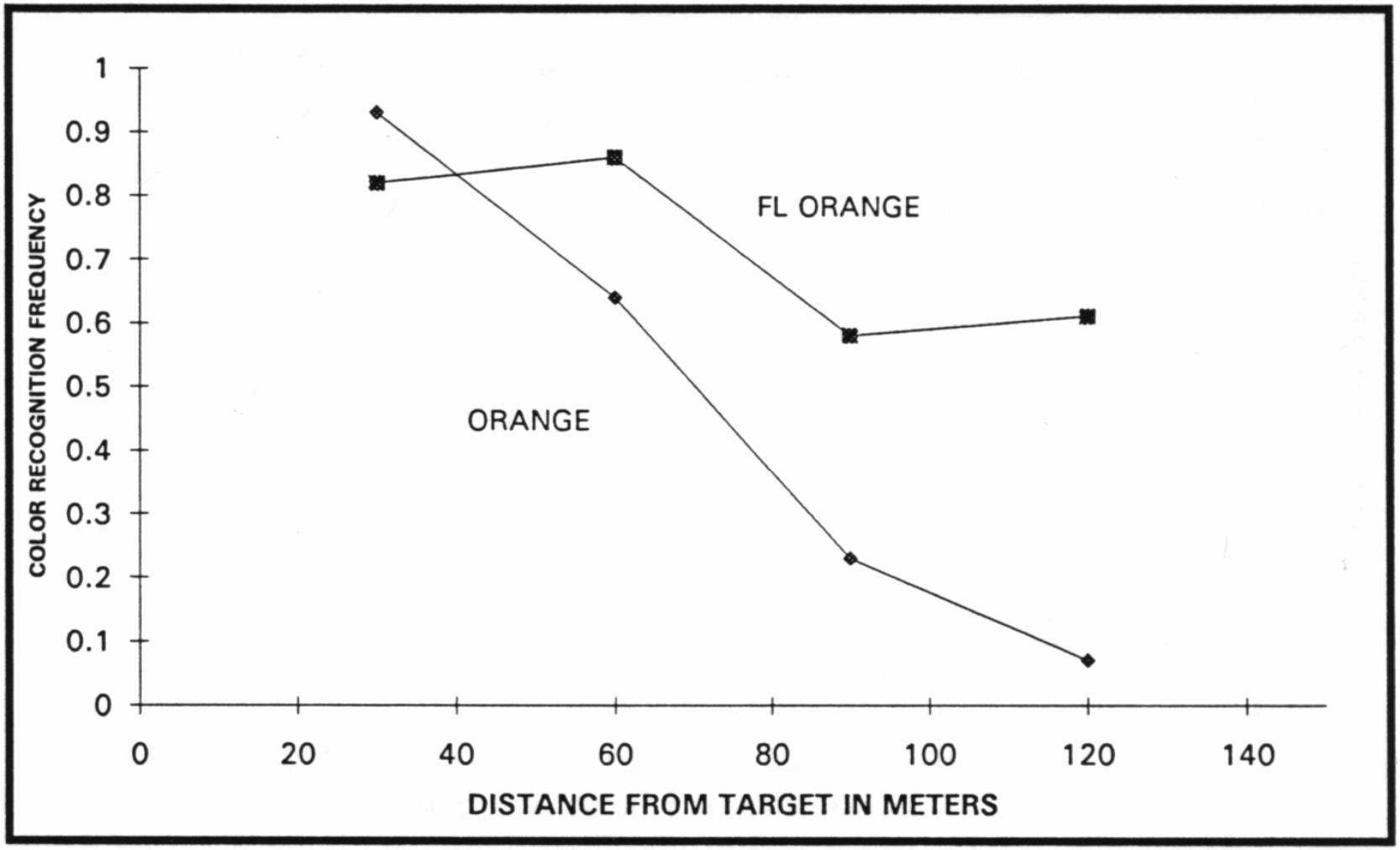
Burns & Pavelka (1995)
Detection Performance



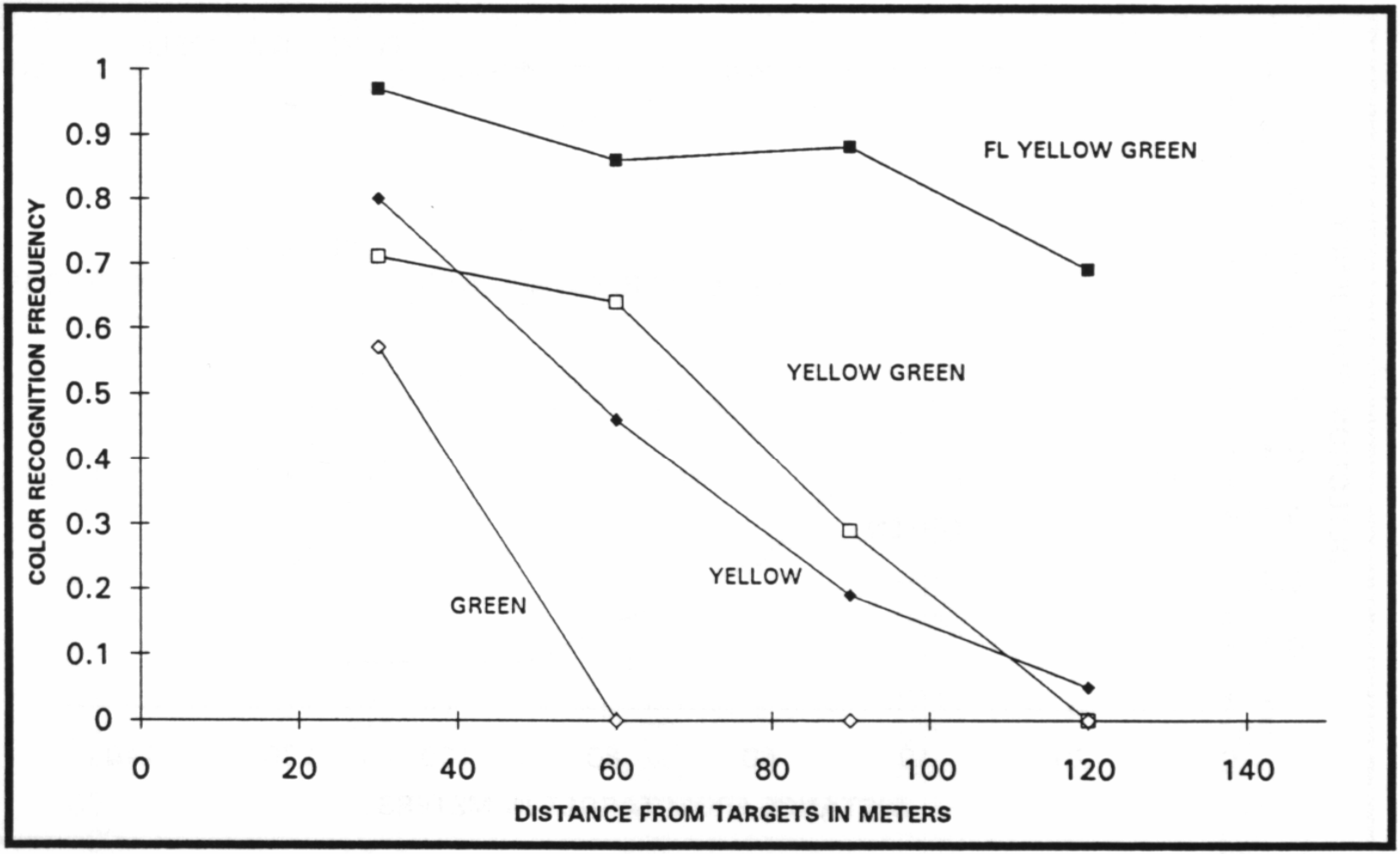
Burns & Pavelka (1995)
Detection Performance



Burns & Pavelka (1995)
Recognition Performance

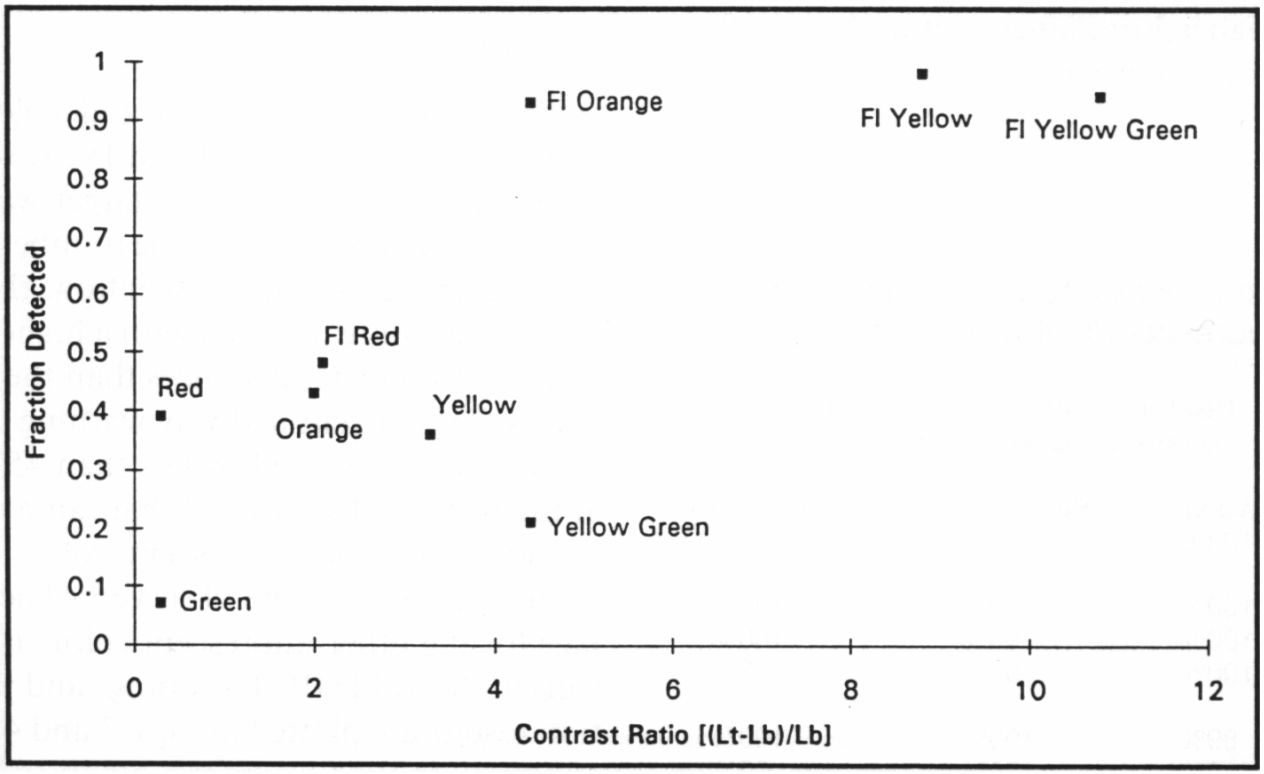


Burns & Pavelka (1995)
Recognition Performance



Burns & Pavelka (1995)

Fluorescent targets had higher luminance contrast against the multi-colored background



Burns & Johnson (1997)
Appearance at Dusk

- Investigated possible photometric mechanism for apparent increase in relative conspicuity of fluorescent signs at dusk and under overcast sky
- Fluorescent: Orange, Yellow, Yellow-Green
- Subjective rating of brightness (lightness)
- 1 hour before - half hour before sunset

Changes in Perceived Lightness and Luminance Contrast approaching and following sunset

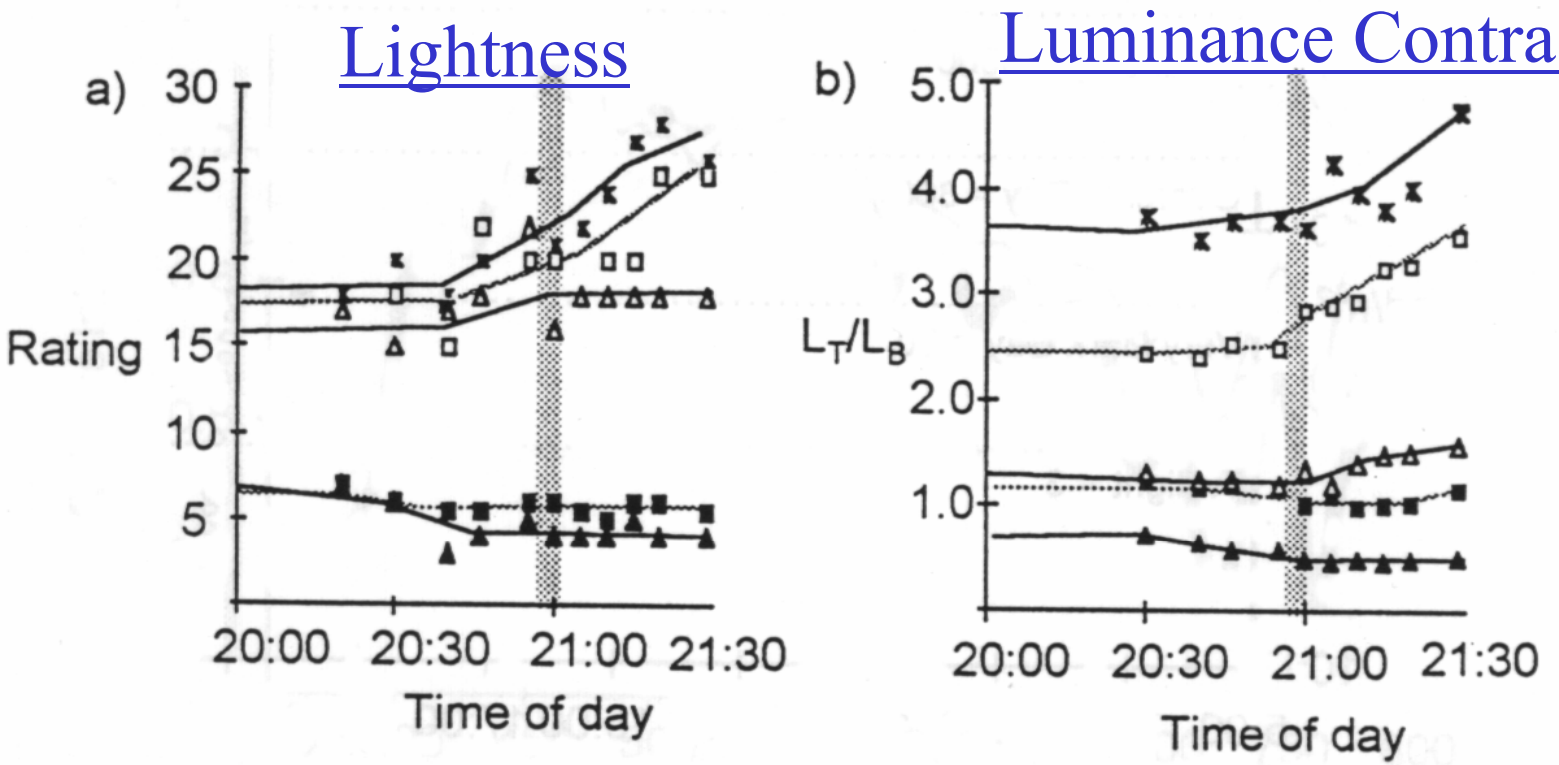


Fig. 2: Brightness perception experiments. a) Brightness rating versus time; b) Luminance contrast ($L_{target}/L_{background}$) versus time. Fluorescent yellow green (×), fluorescent yellow (□), ordinary yellow (■), fluorescent orange (△), ordinary orange (▲). Sunset = 21:00.

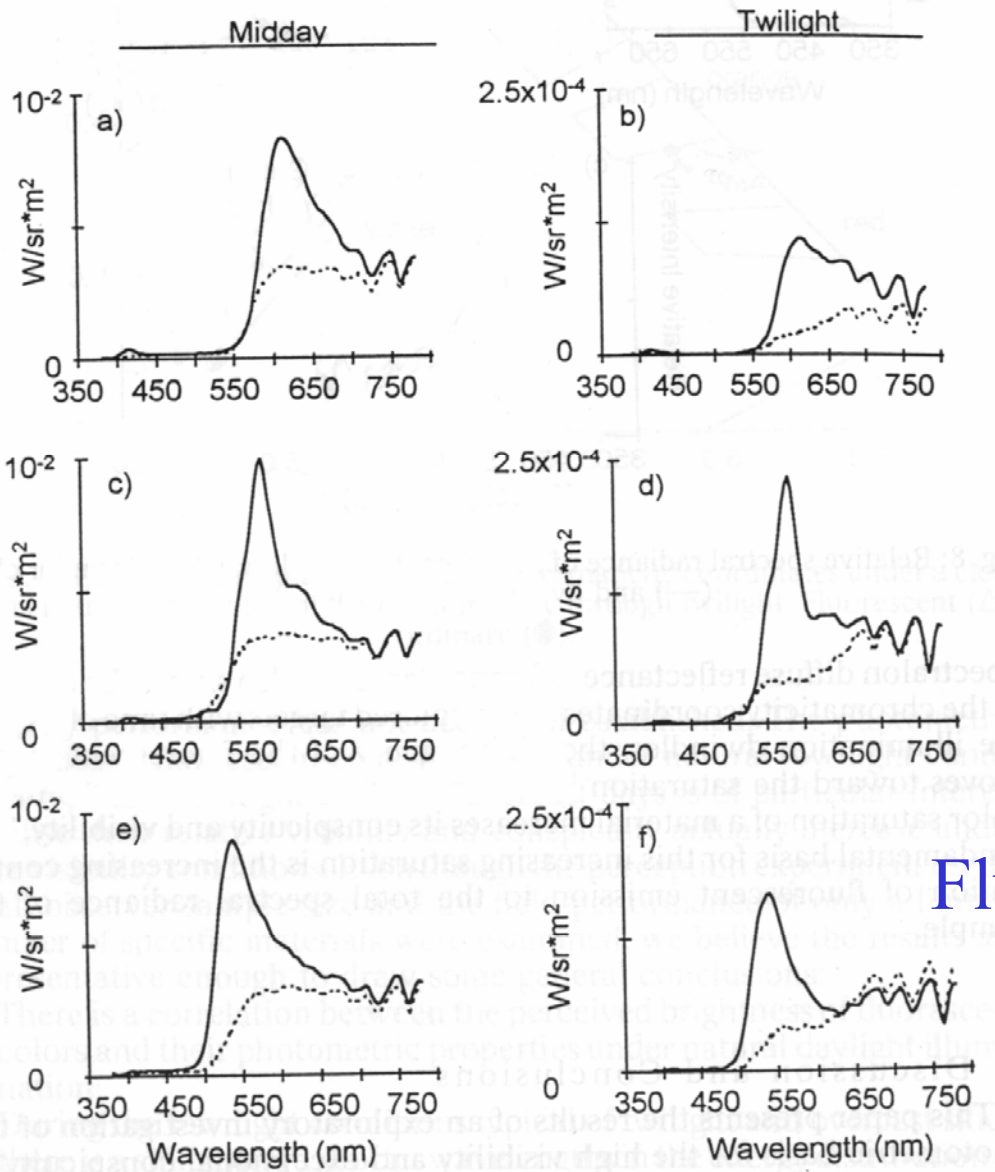


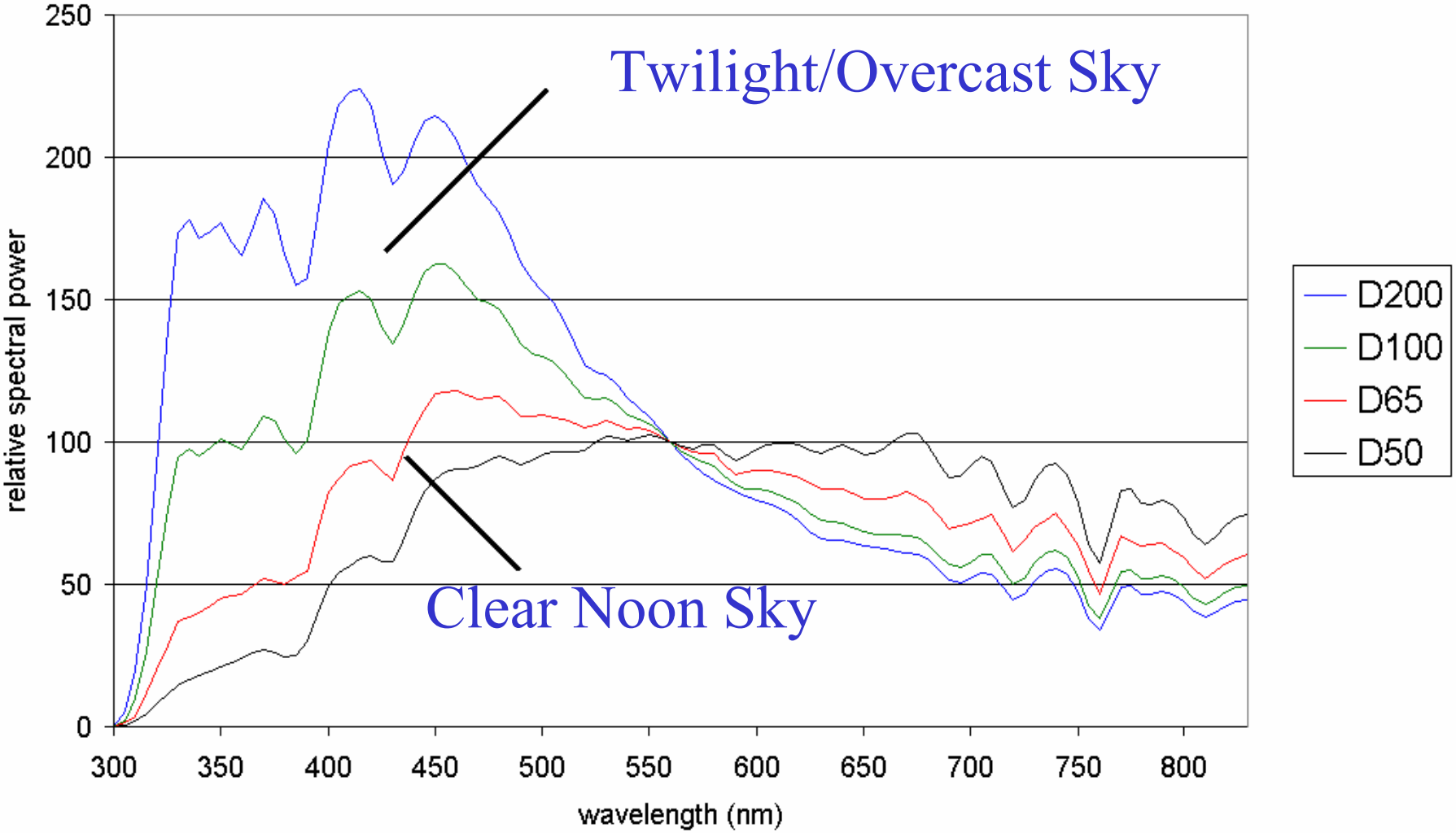
Fig. 7: Spectral radiances of colored targets under clear sky at midday and twilight: Fluorescent (—); ordinary (- - - - -). a) and b) Fluorescent orange vs. ordinary orange; c) and d) fluorescent yellow vs. ordinary yellow; e) and f) fluorescent yellow green vs. ordinary yellow.

Fluorescent Orange versus Orange

Fluorescent Yellow versus Yellow

Fluorescent Yellow-Green versus Yellow

Four Phases of Daylight



Relative Spectral Radiance Distributions under Clear versus Overcast Skies

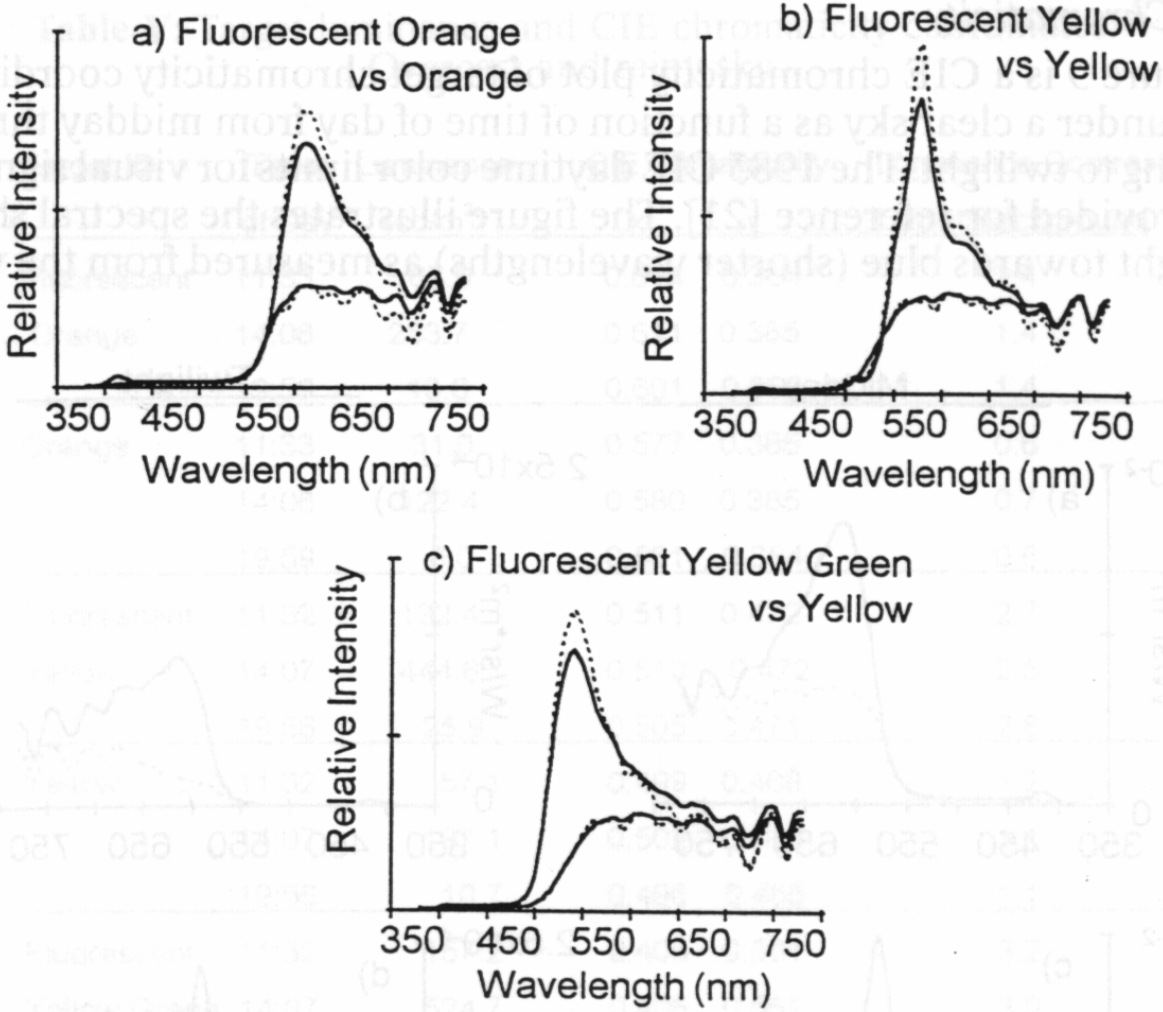
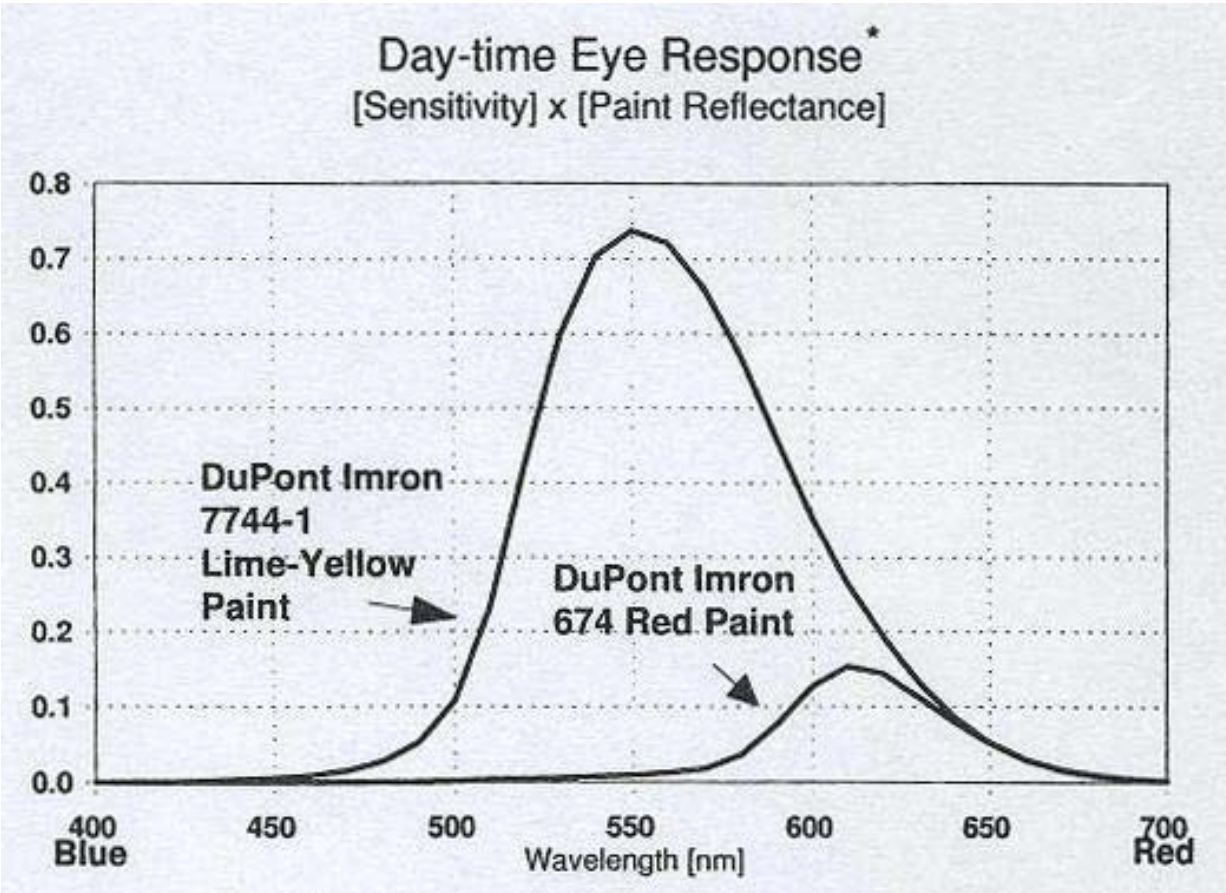


Fig. 8: Relative spectral radiance of fluorescent and ordinary targets under clear (—) and overcast skies (- - - - -).

Solomon & King (1997)

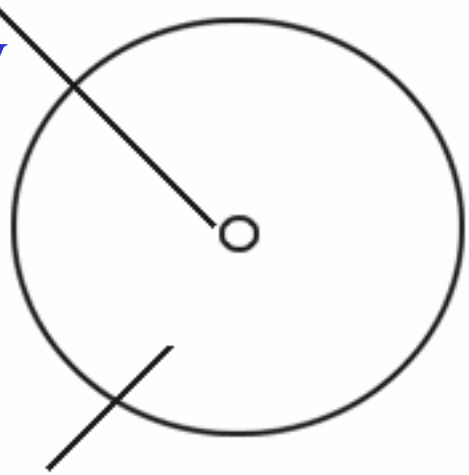
Dallas Fire Dept (Emergency Vehicle Crashes: 1984-88)
Significantly fewer crashes for Lime Green vehicles
(compared to Red or Red & White Fire Trucks)



Fluorescent Appearance: Some Theoretical Considerations

Evans' (1959; 1974) Stimulus Configuration

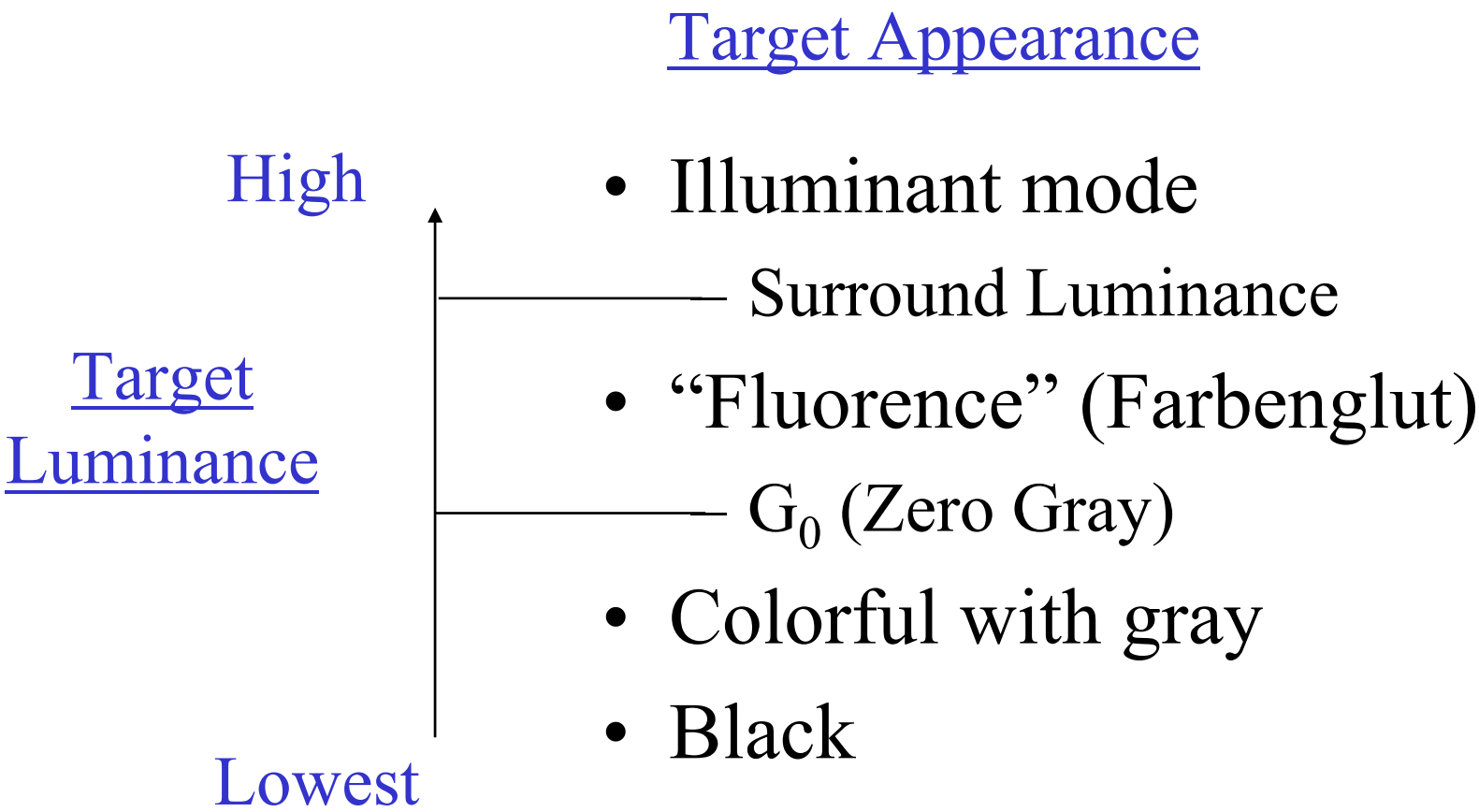
1° Test Field
Variable Luminance
Constant chromaticity



10° Achromatic Surround
Constant Luminance (318 cd/m^2)

Evans' Fluorence Threshold

G_0 = log(Surround/Target Luminance)



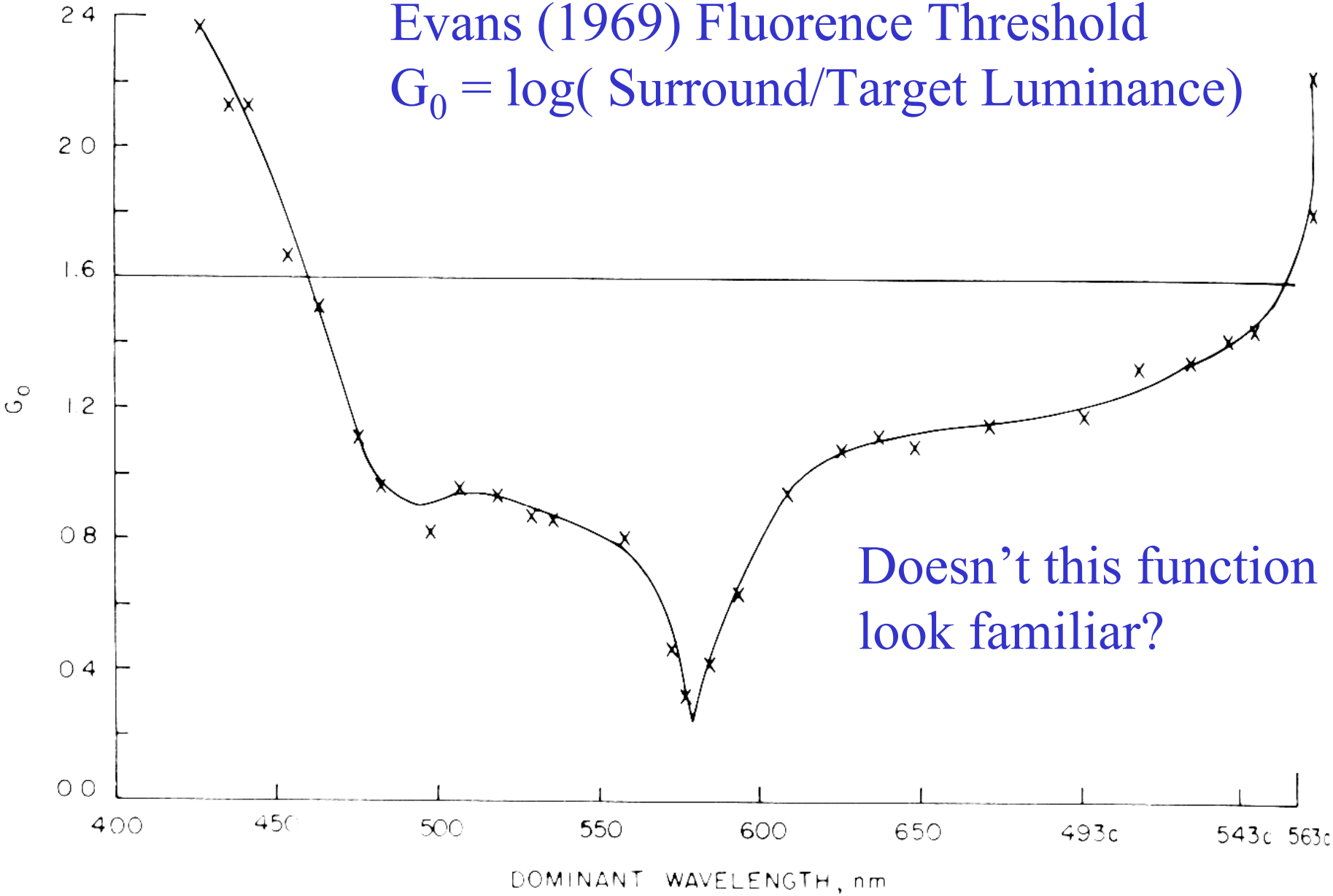


Fig. 7-1. G_0 as function of stimulus monochromatic wavelength with achromatic (C. 7000 K) surround at 100 mL (corrected for stimulus purities: observer RME). (From *J. Opt. Soc.* **59**, 633, 1969).

Spectral Saturation Function

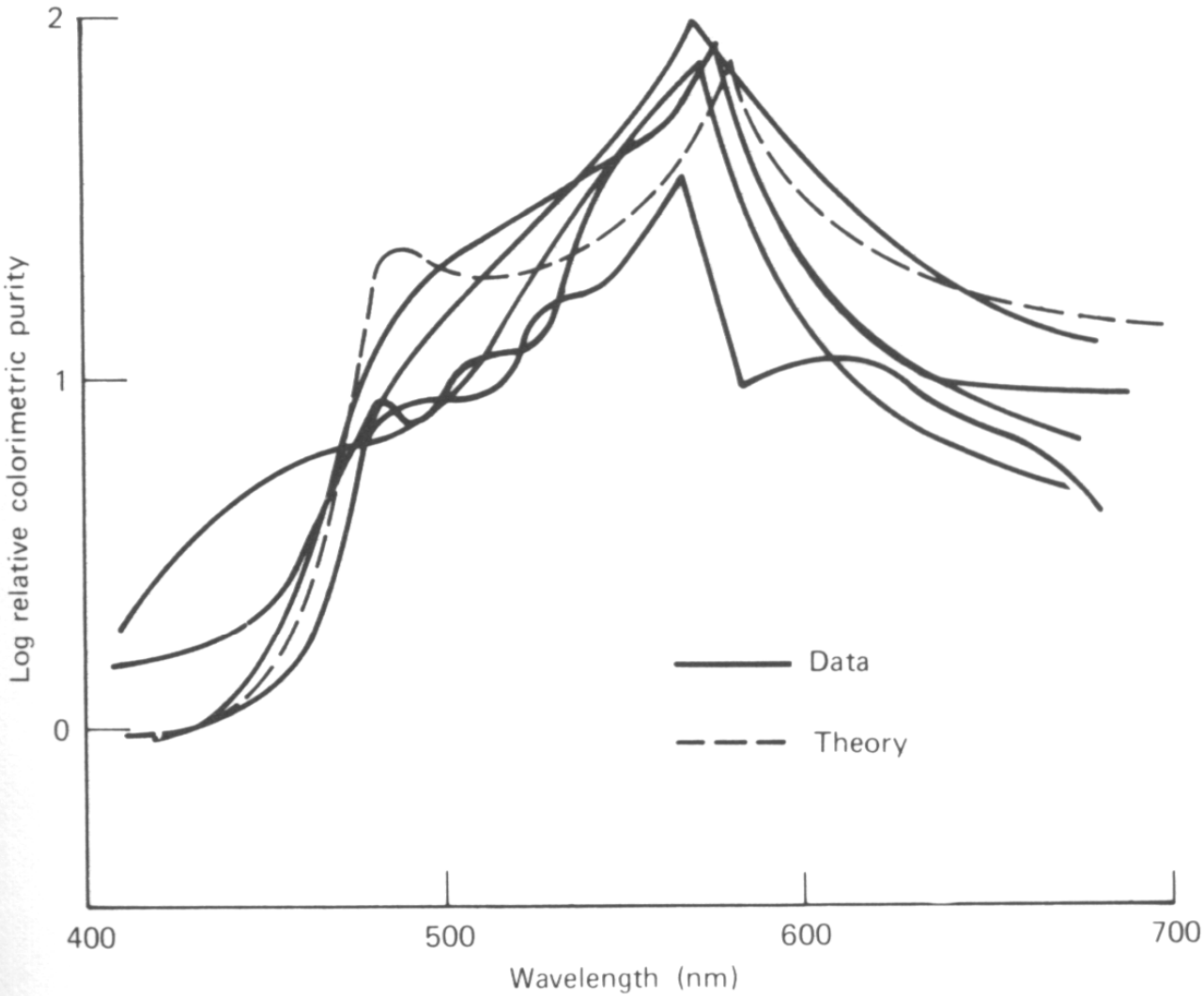
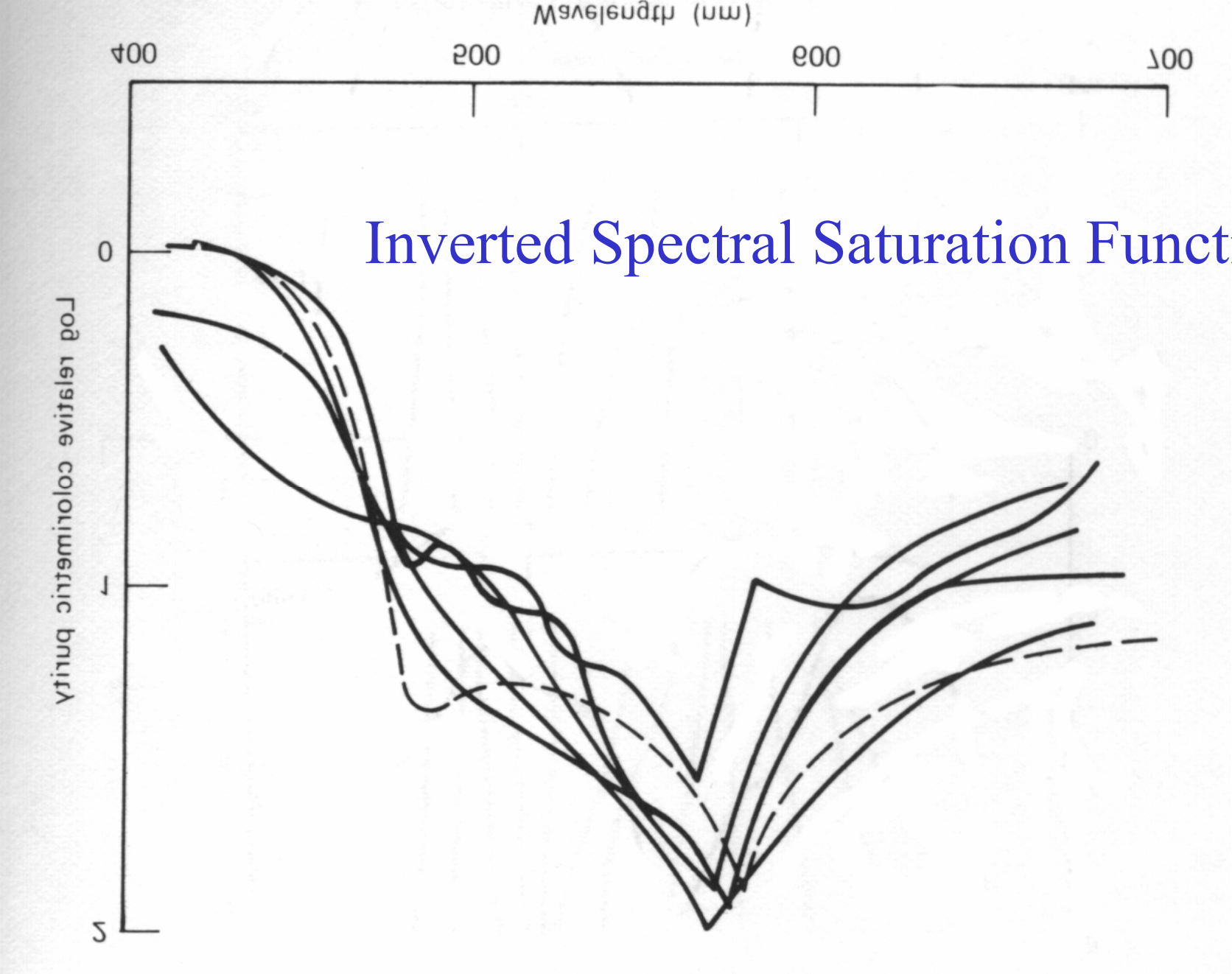


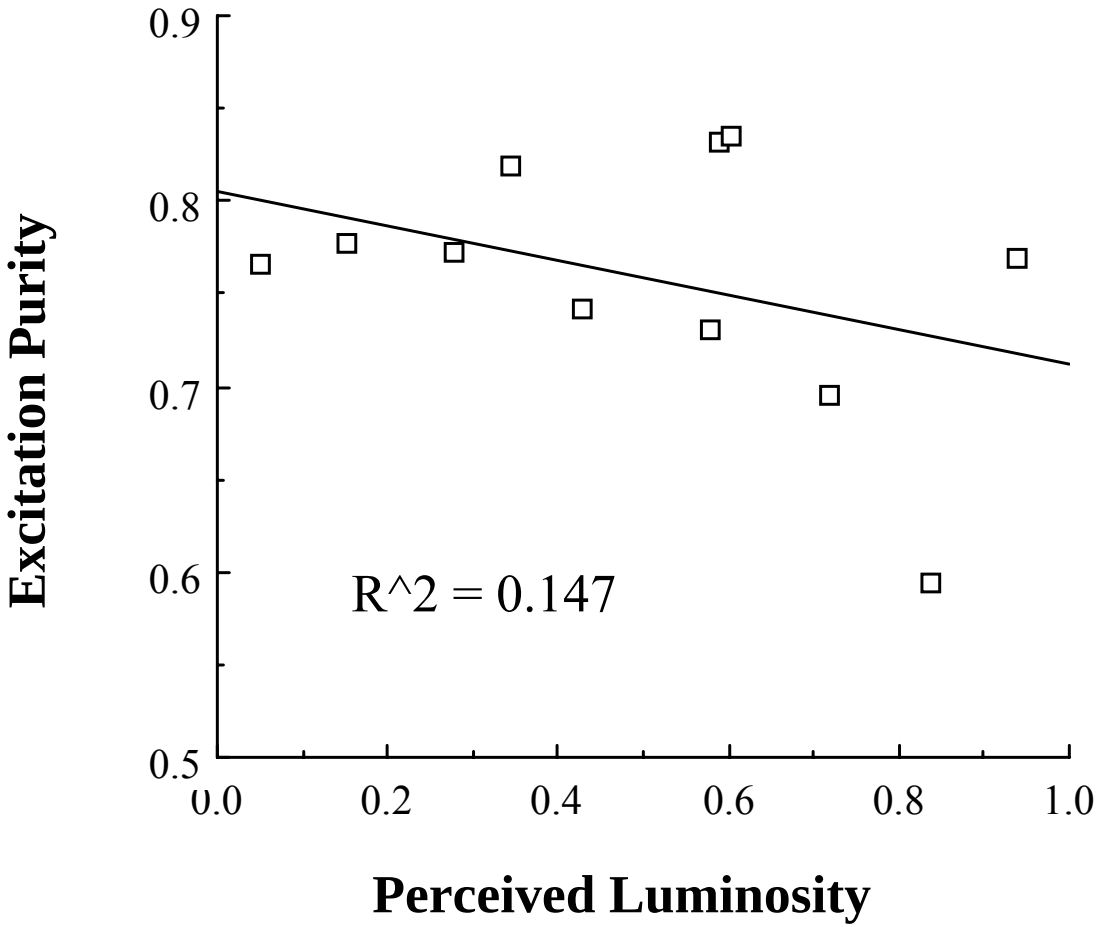
Figure 7-9. Theoretical and experimental spectral-saturation functions. The dashed curve represents the saturation functions predicted by opponent response theory as quantified by Hurvich and Jameson. The other functions indicate five separate measurements of this behavior in five different observers. The agreement between theory and experiment is as good as the experimental variability will permit. (After Hurvich and Jameson, 1957.)



Inverted Spectral Saturation Function

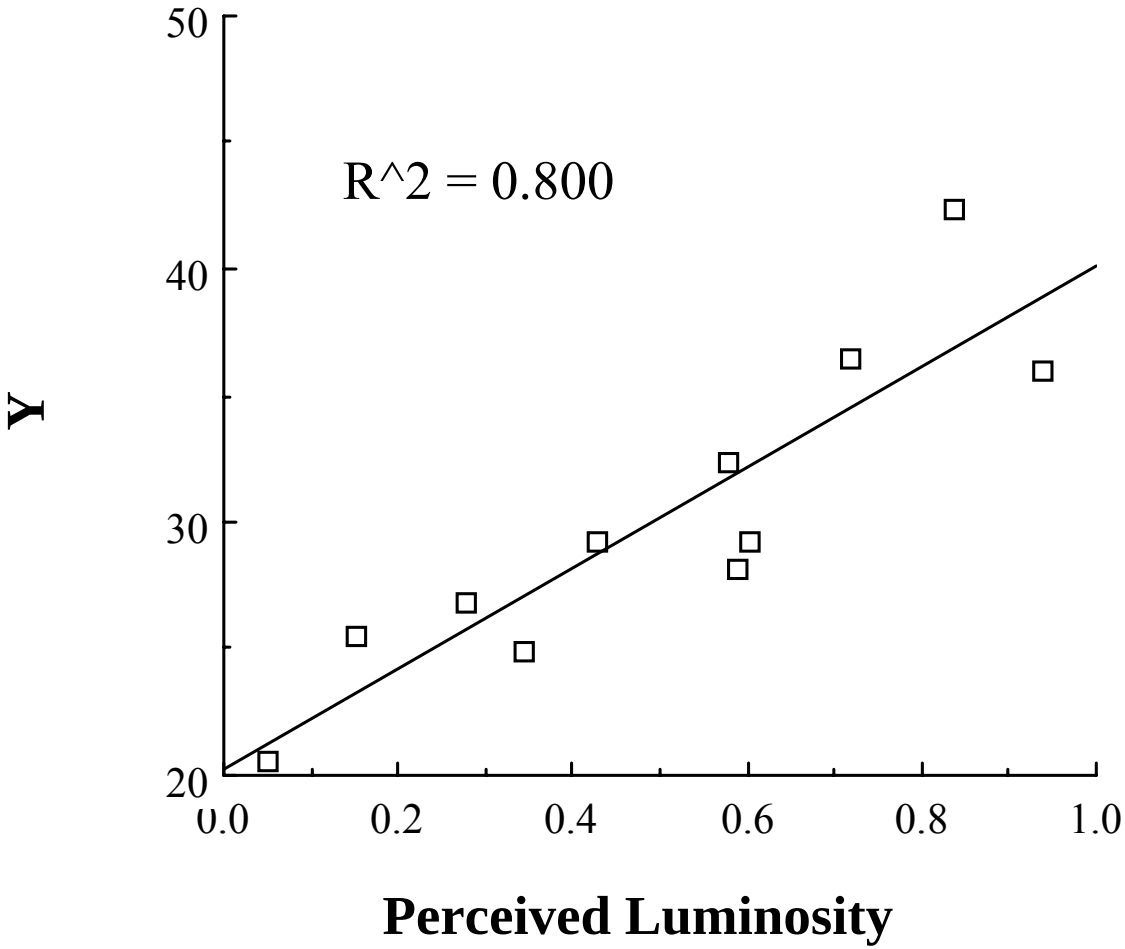
Modeling Appearance Data for Targets of Variable Fluorescence

Perceived Luminosity as a function of Excitation Purity (i.e., Saturation)



(Data from Thielert & Schliemann, JOSA, 1972)

Perceived Luminosity as a function of Total Luminous Reflectance (Y)



The MacAdam Limit (Y_{max} for a given Chromaticity)

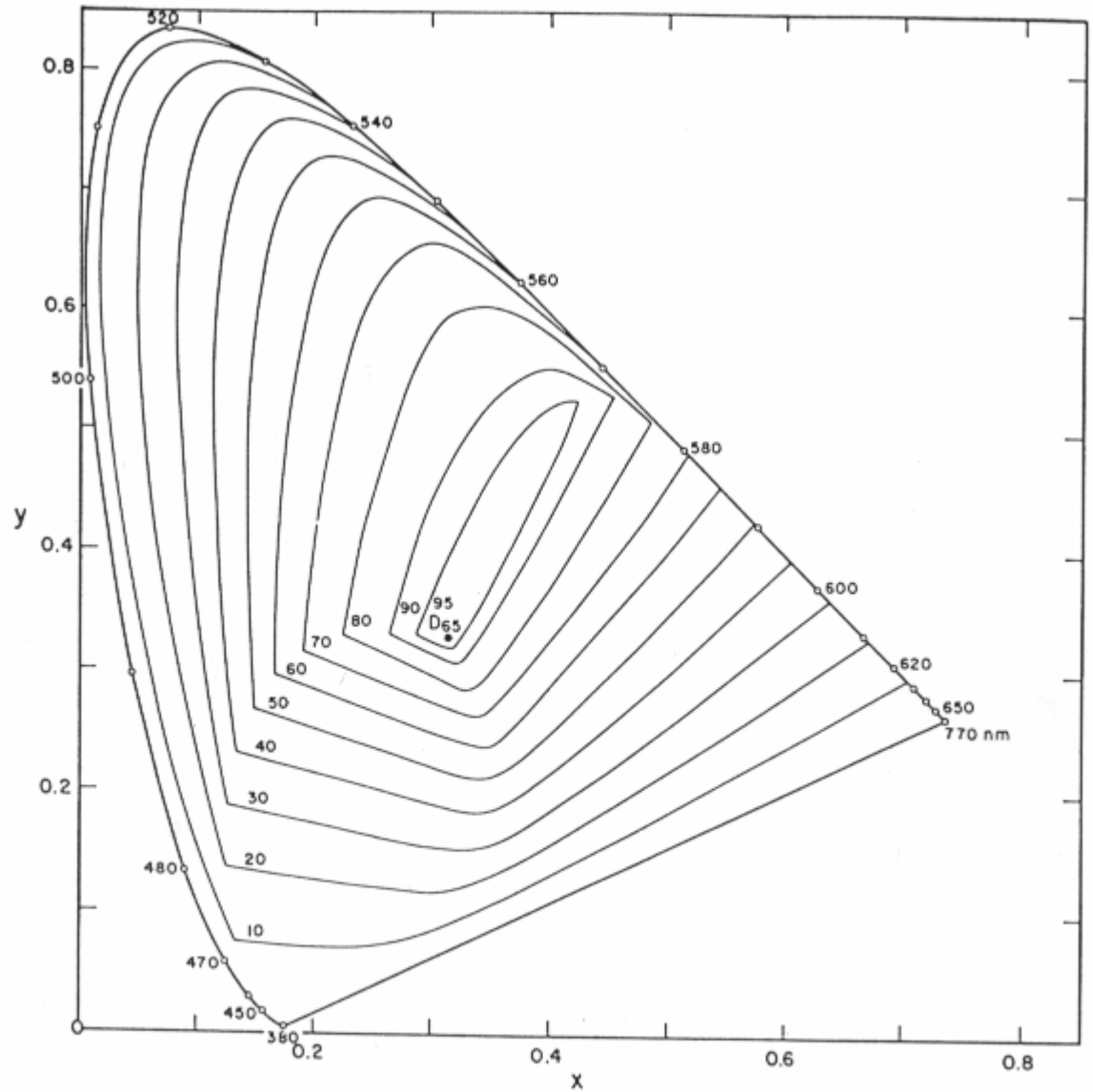


Fig. 4(3.7). Chromaticity loci of optimal color stimuli as a function of Y, on the basis of the CIE 1931 standard observer and for incident radiant power from the CIE standard illuminant D_{65}.

3D MacAdam Limit Surface

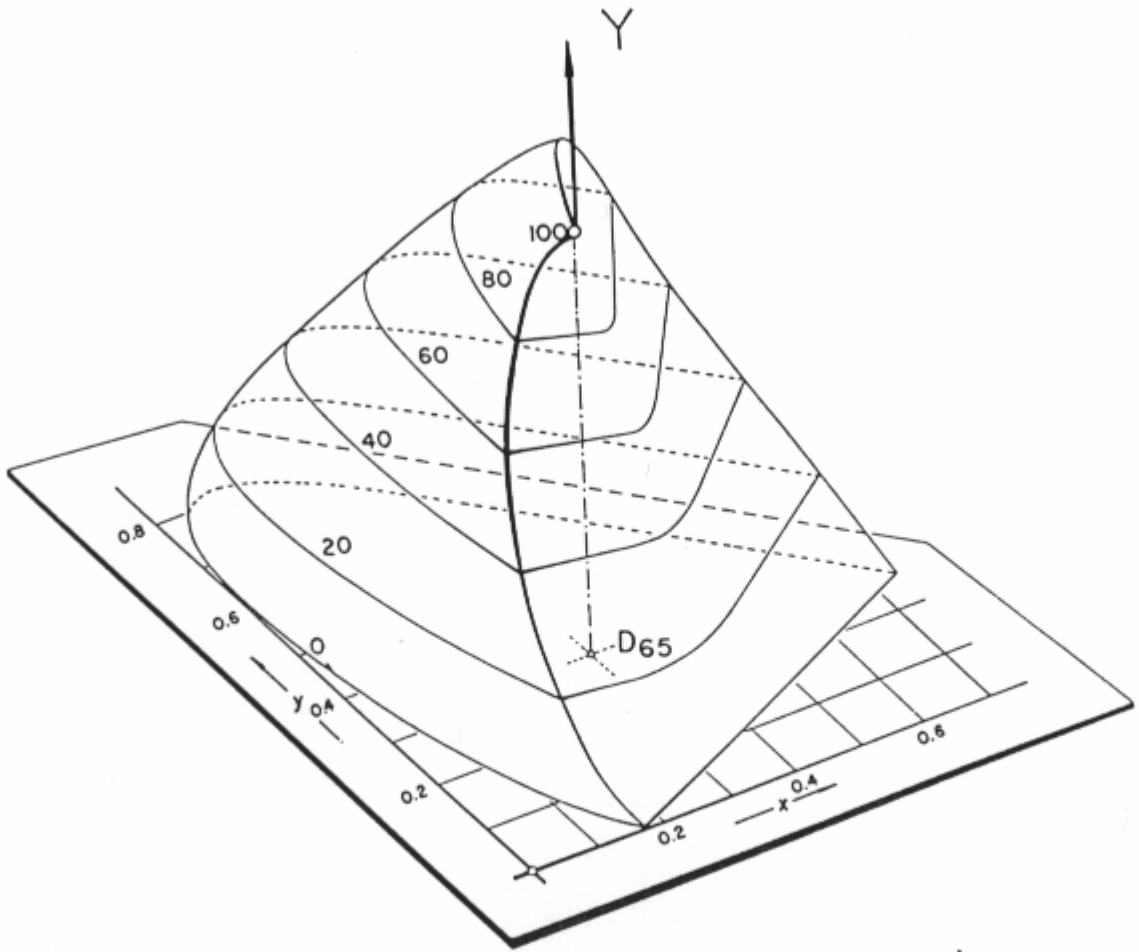
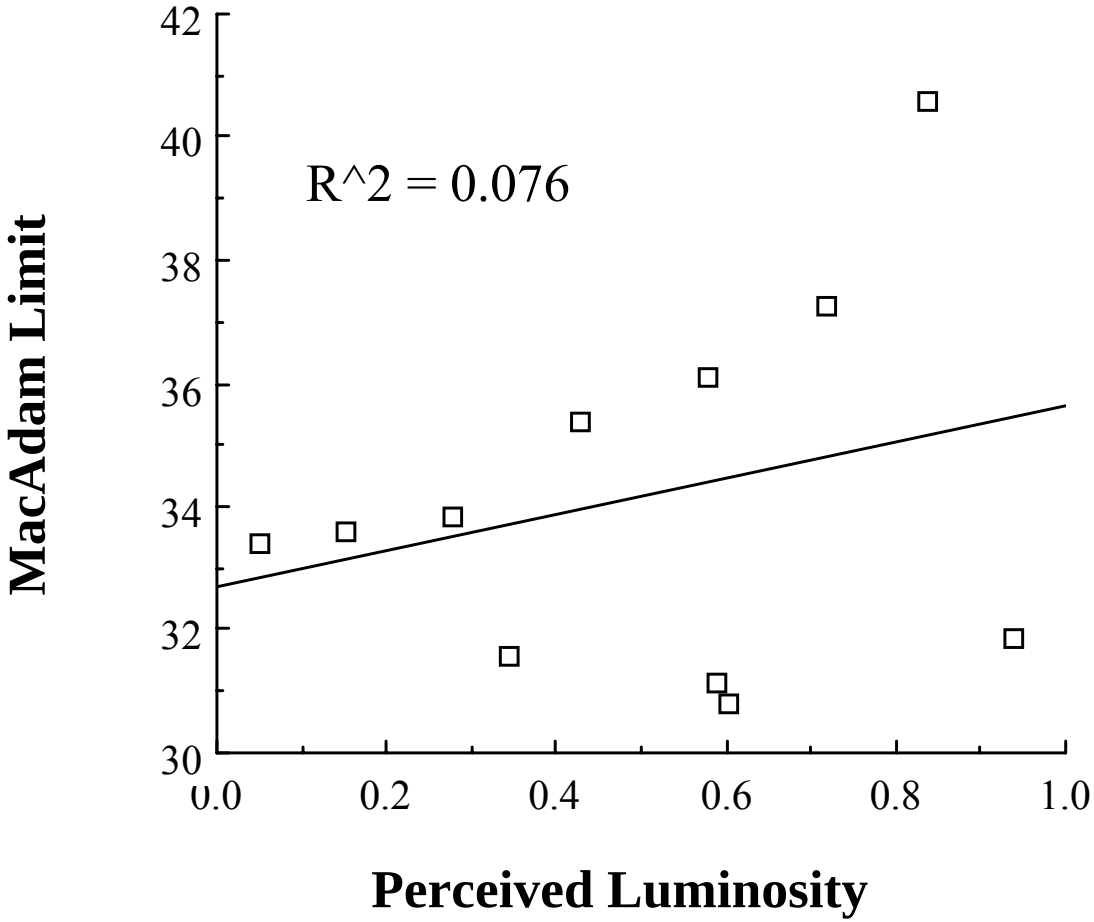
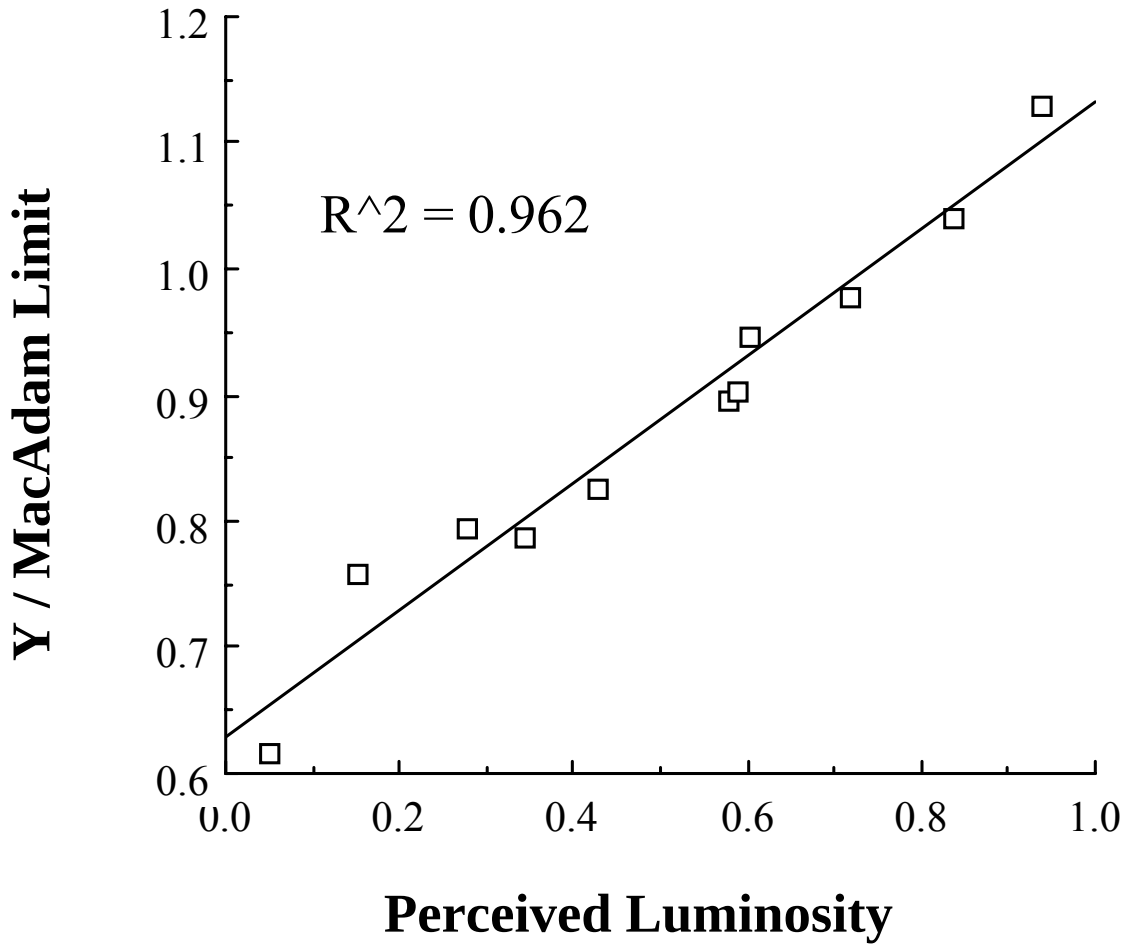


Fig. 5(3.7). Oblique projection of the (x, y, Y) object-color solid showing the boundary surface representing the optimal color stimuli (Rösch color solid).

Perceived Luminosity as a function of the MacAdam Limit for Target Chromaticity (x,y)



Perceived Luminosity as a function of Total Luminous Reflectance (Y) normalized to the MacAdam Limit



Perceptual Basis for the Fluorescent Advantage

Central Claim of TRB 2001 Session on Fluorescent Signs

Fluorescent colors “grab your attention”

This central assumption may actually be true but it has not yet been convincingly demonstrated experimentally...

Psychological Mechanisms of Visual Conspicuity

Visual Search Paradigm

A powerful link between the cognitive sciences and any attempt to understand highway sign conspicuity….Yet, little work has been done to leverage this potentially rich resource of data and theoretical mechanisms...

Visual Search Paradigm

Slow/Serial Search

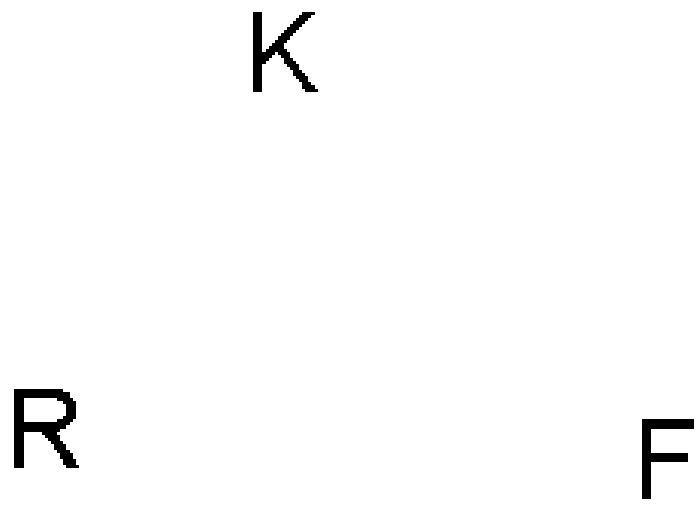
vs.

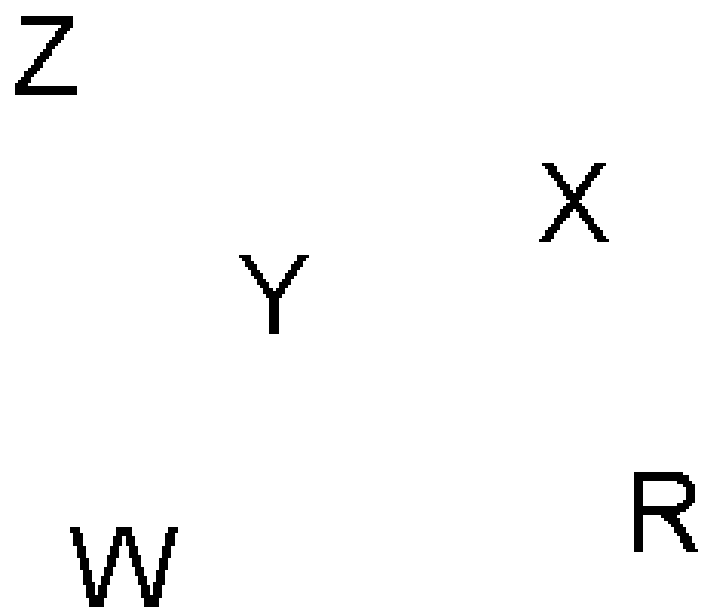
Fast/Parallel Search

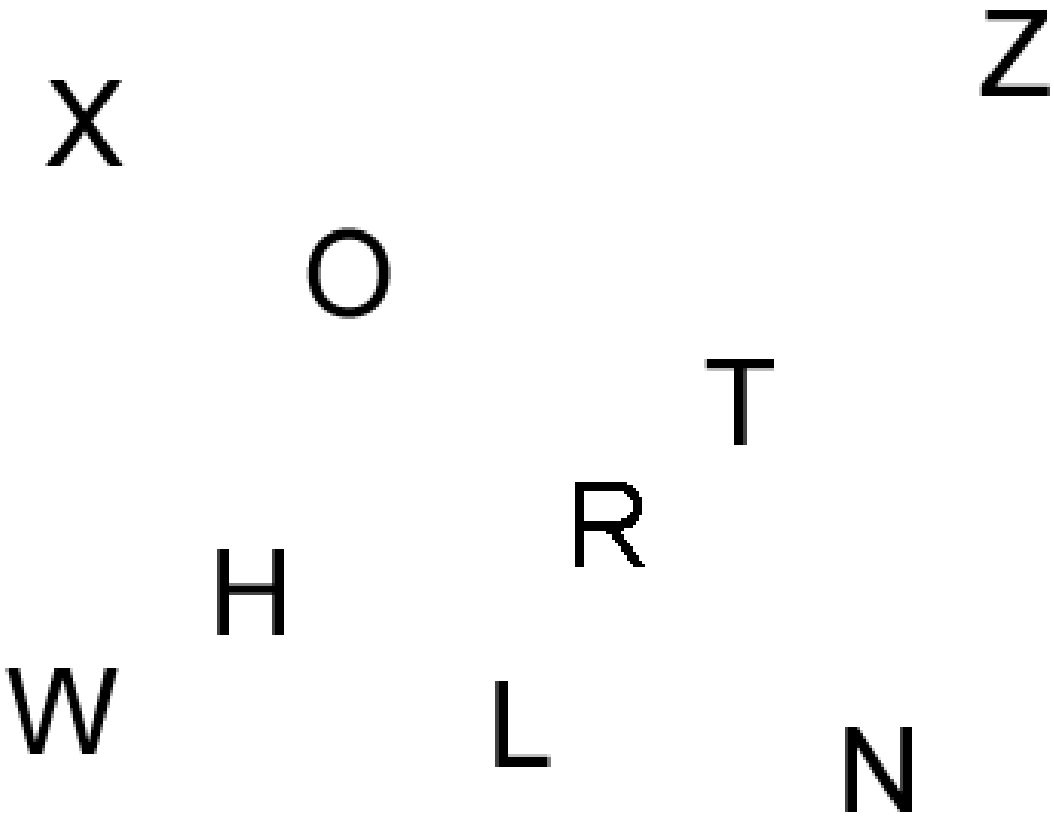
Raise your hand when you find the letter “R”

R

X


K
R
F


Z
X
Y
R
W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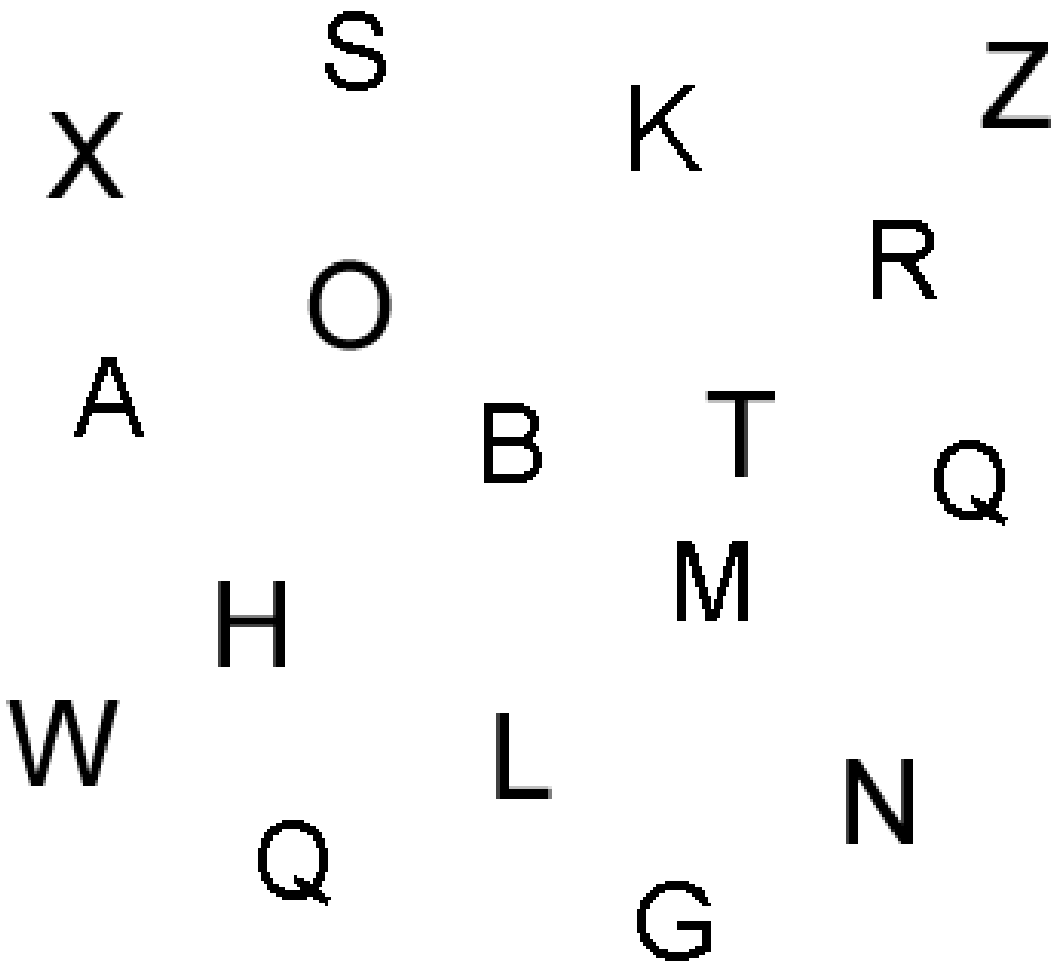
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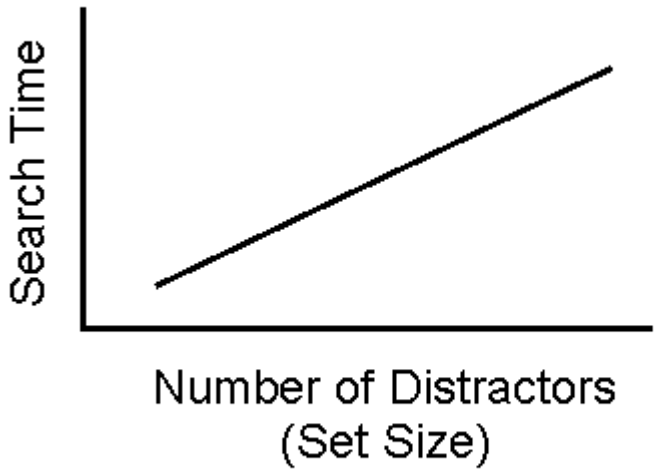
When no unique perceptual cue is available, visual search involves an item-by-item evaluation

i.e., Slow/Serial Search
(top-down item-by-item evaluation)



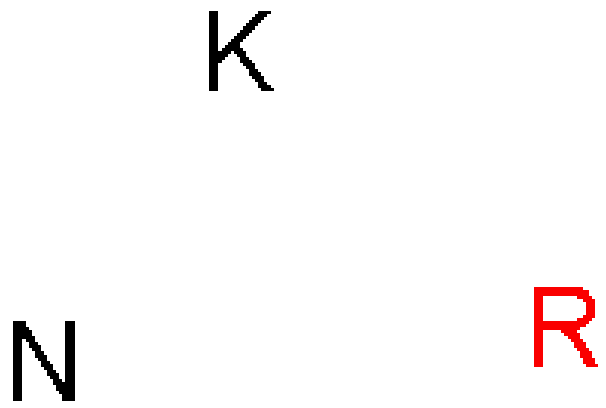
Visual Search Paradigm

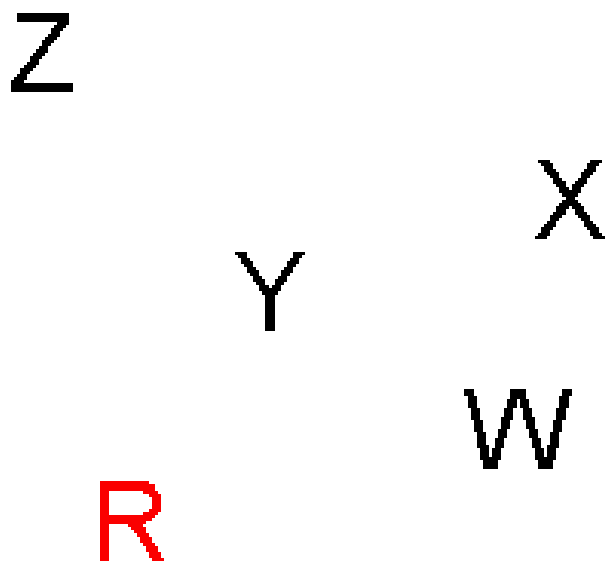
Fast/Parallel Search

(bottom-up perceptual segregation of "target")

Raise your hand when you find the letter "R"


R
X


K
N
R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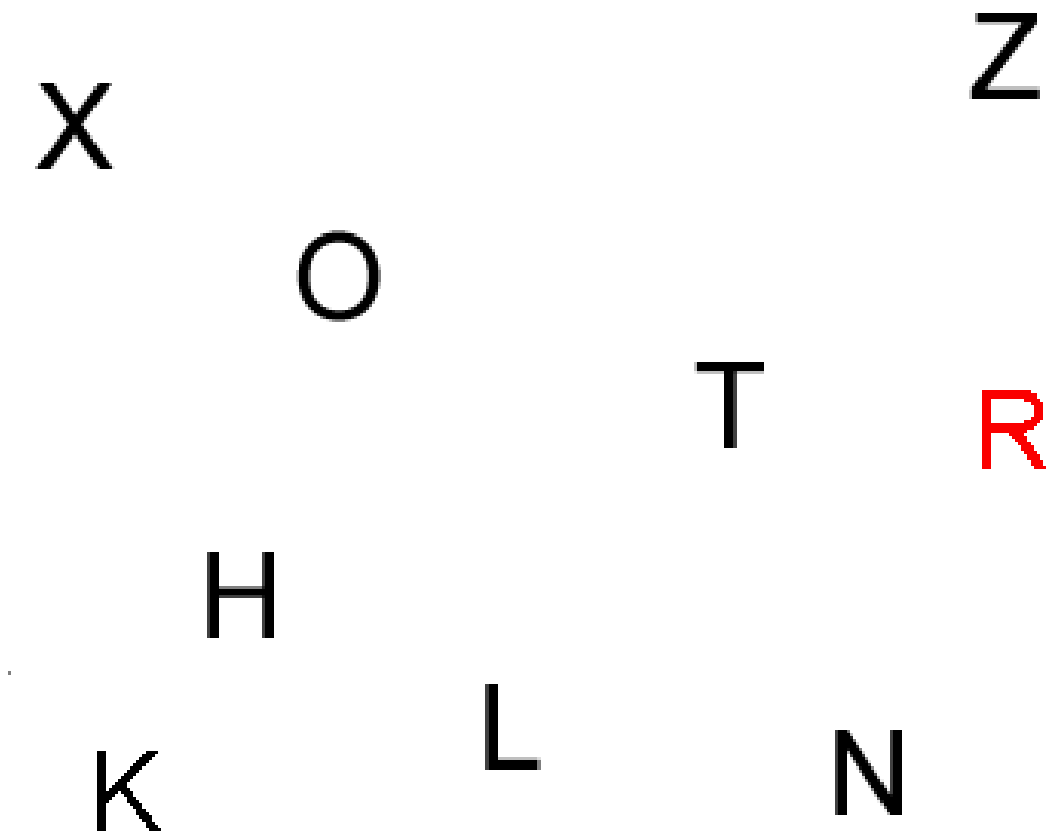
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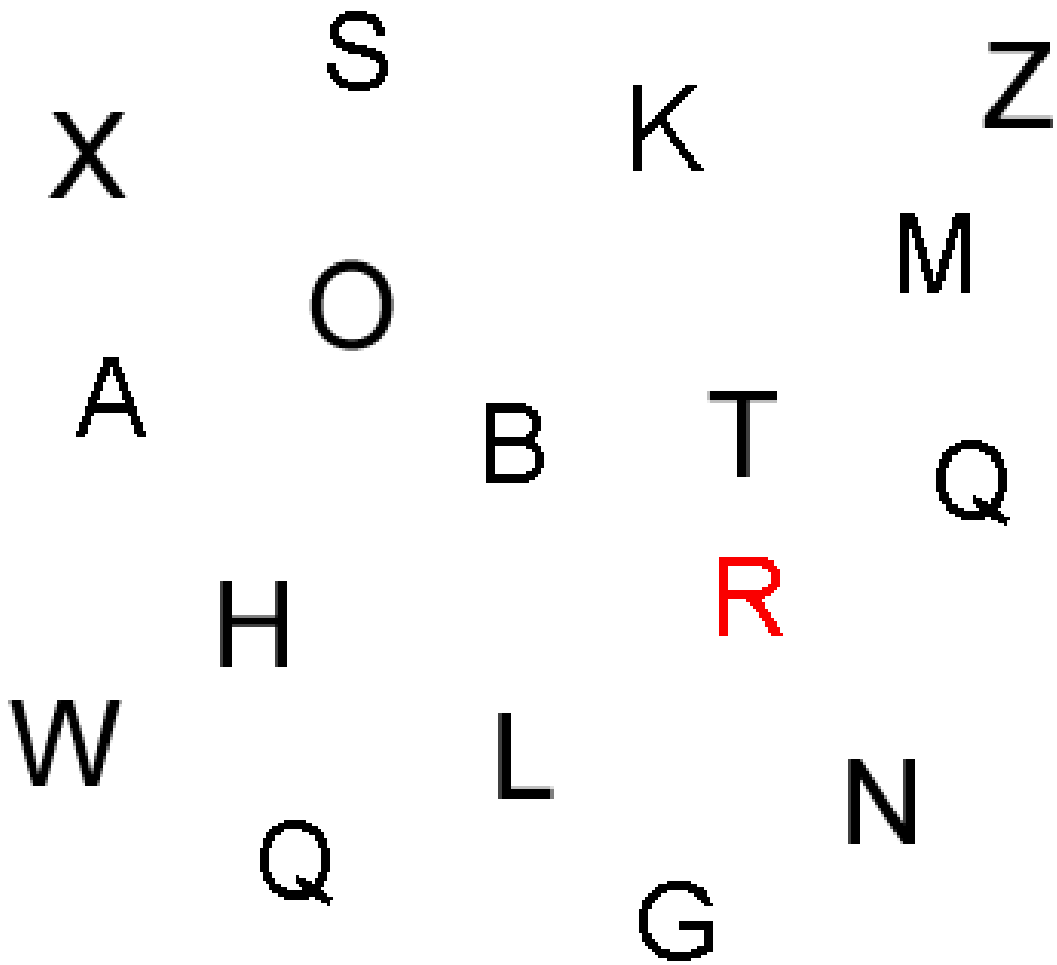
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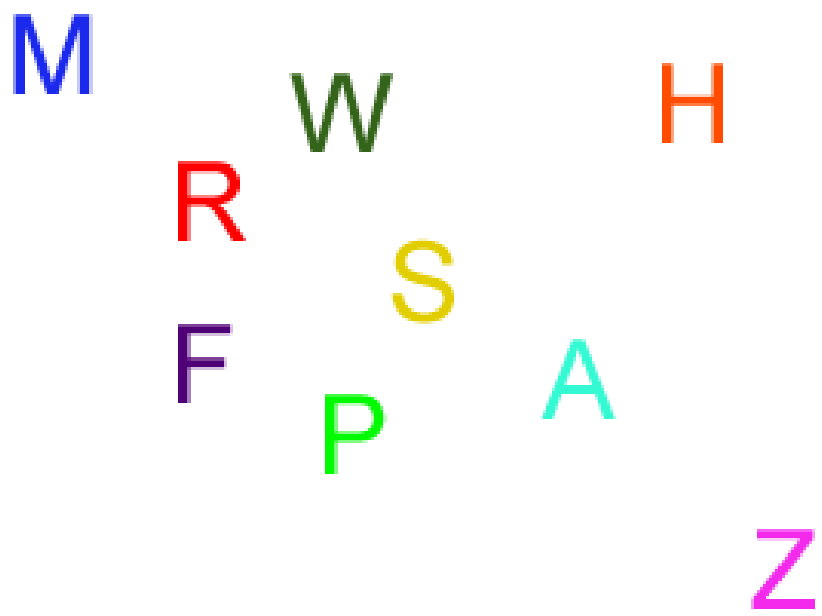
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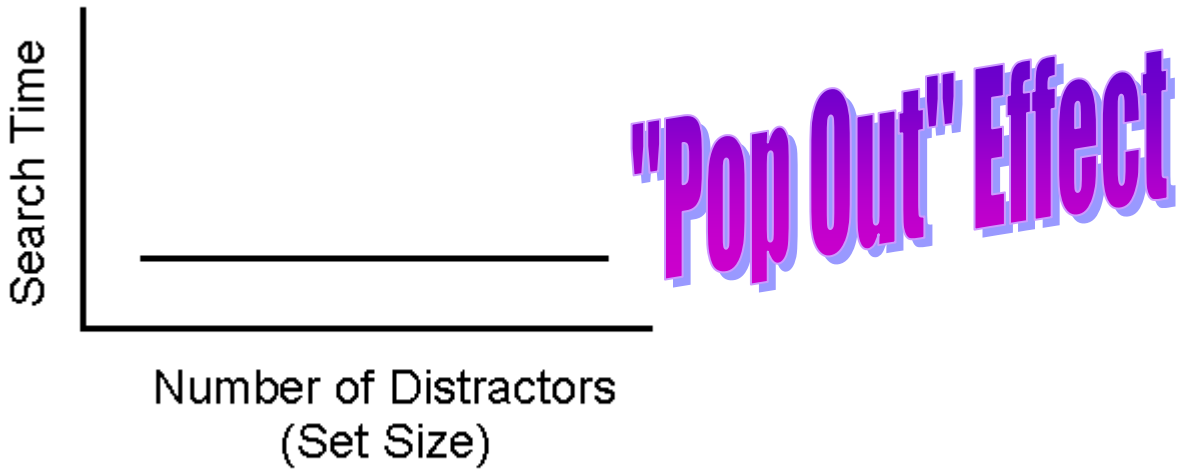
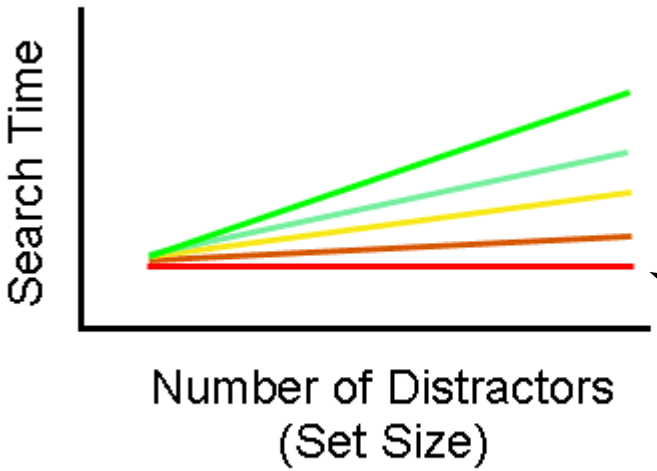
When a unique perceptual cue is available, the entire visual scene can be "evaluated" simultaneously

i.e., Fast/Parallel Search



Relative Search Efficiency Models



Low efficiency
(slow/serial)
(top-down limited)

High efficiency
(fast/parallel)
(bottom-up limited)

Recent Laboratory Studies

University of South Dakota

Research Questions

- Do fluorescent colored signs "pop out" or provide other advantages for visual search?

  If so….Why? (i.e., What's the mechanism?):
- Attentional conspicuity advantage?
- Search conspicuity advantage?
- Both of the above?

Attentional Conspicuity

- Stimulus property that automatically and involuntarily recruits the locus of attention ("grabs" your attention)
- perceptual (preattentive; not cognitive)
- bottom-up ("stimulus-driven")
- effortless and fast

Examples: abrupt luminance transients; motion

Search Conspicuity

- Stimulus property that contributes to the efficiency of "guided" search processes
- Selective allocation of attention to perceptually constrained information channels
- top-down ("task-driven")
- nearly effortless and fast

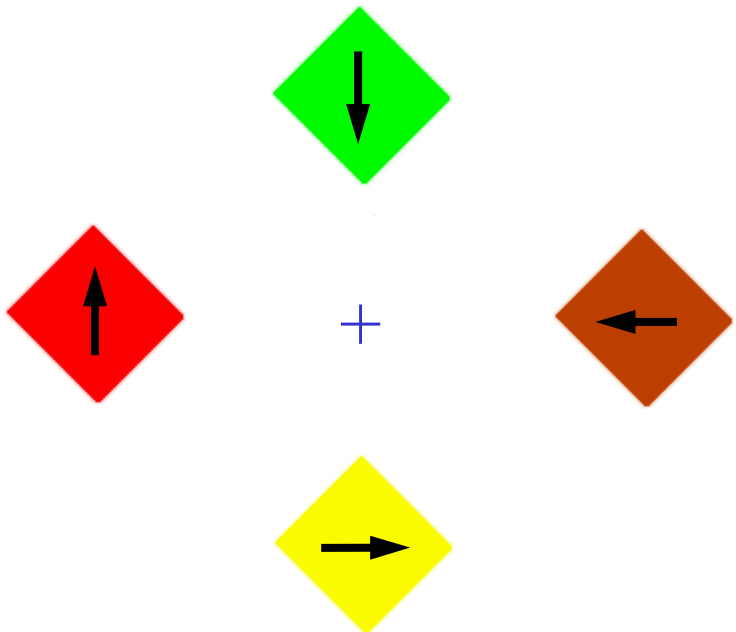
Example: color "singletons"

Search Experiment #1

- Visual Search Task
  (Find the "UP" arrow)
- 4 Distractor Colors
  (red, green, yellow, orange)
- 48 stimulus trials
- Unexpected transition from yellow to fluorescent yellow-green (Trial #33)
- Control condition (Experiment #2)

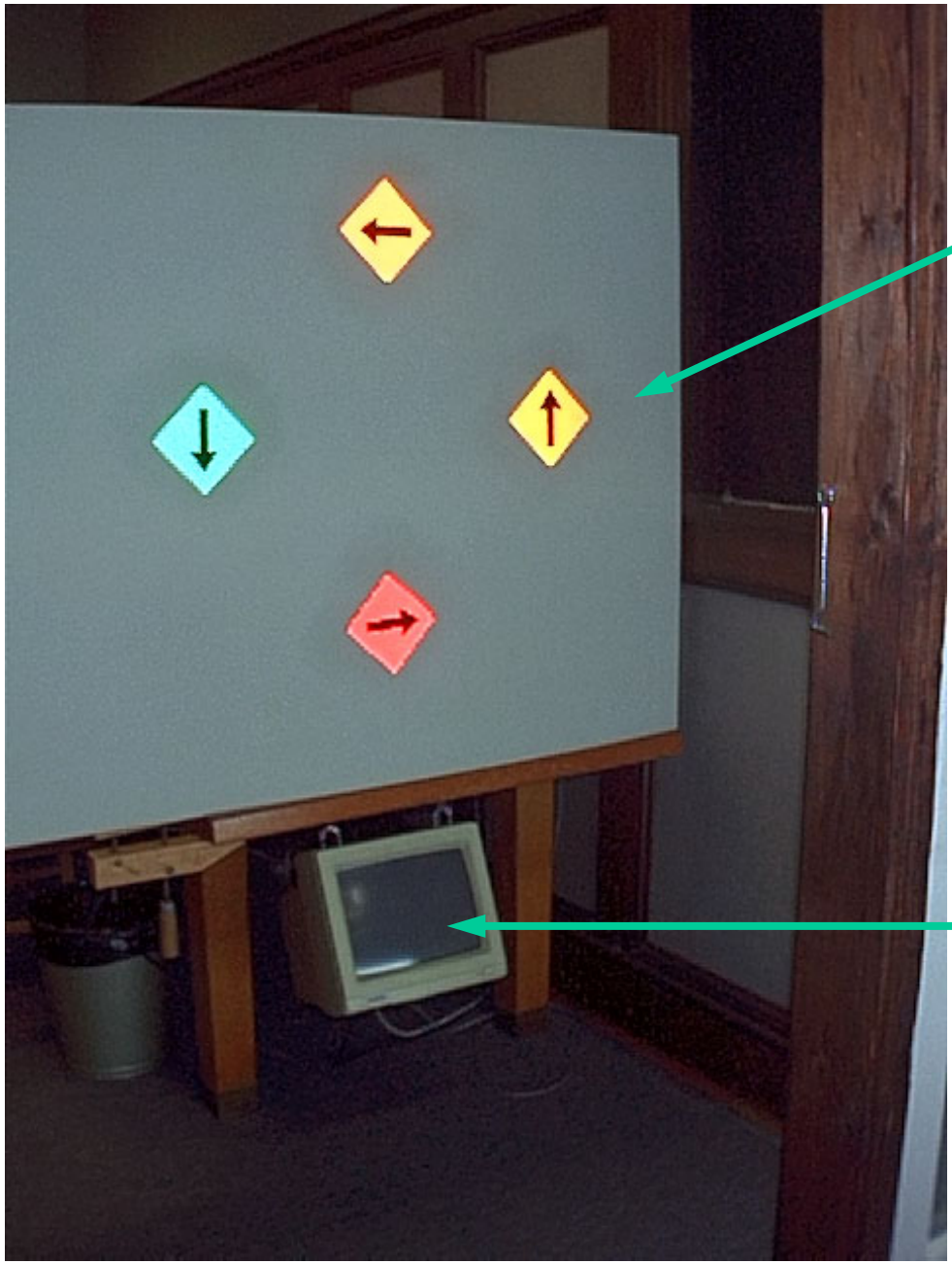
Stimulus Configuration:

5 x 5 inch signs (0.9 degrees); “daylight” illumination; 2.6 degrees from central fixation point; 26 ft distance; random placement of color x arrow combinations; presentation time controlled via *electrochromic window*



Stimulus Photometry

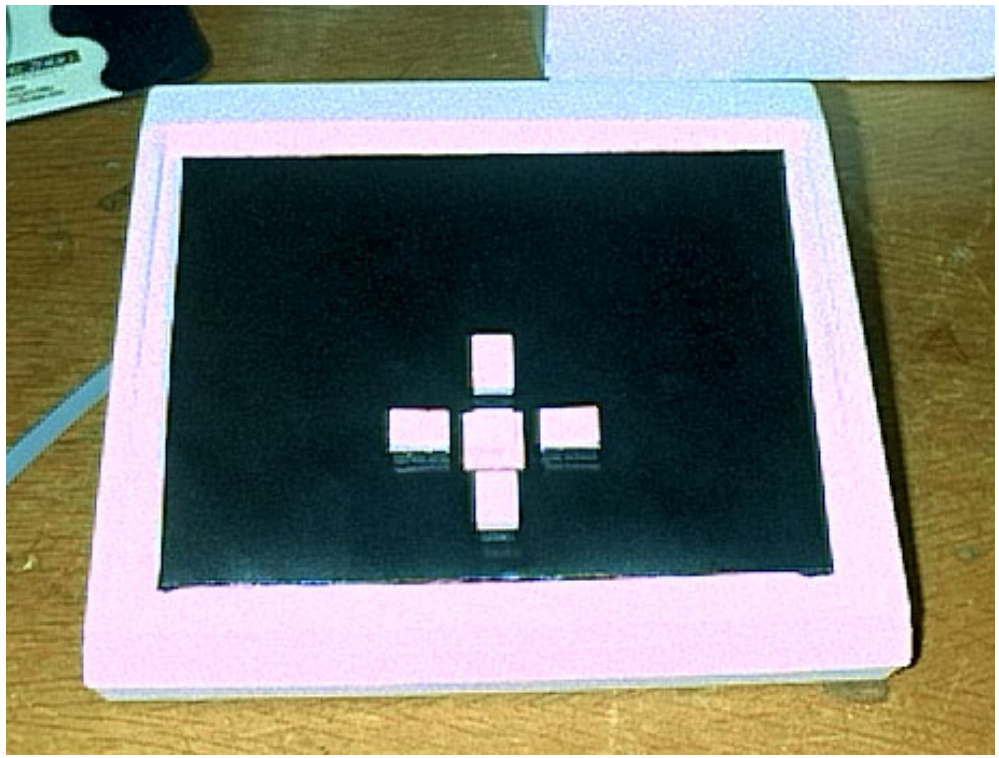
Color	Luminance (cd/m2)	Chromaticity x	y
Red	6.92	0.471	0.305
Green	6.66	0.206	0.361
Yellow	18.88	0.442	0.438
Orange	12.48	0.492	0.363
FluorescentY-G	53.89	0.385	0.544
Fluorescent Red	17.74	0.586	0.603
Fluor. Yellow	36.55	0.489	0.447



Magnetic Stimulus Mounting Board with "D65" Illumination

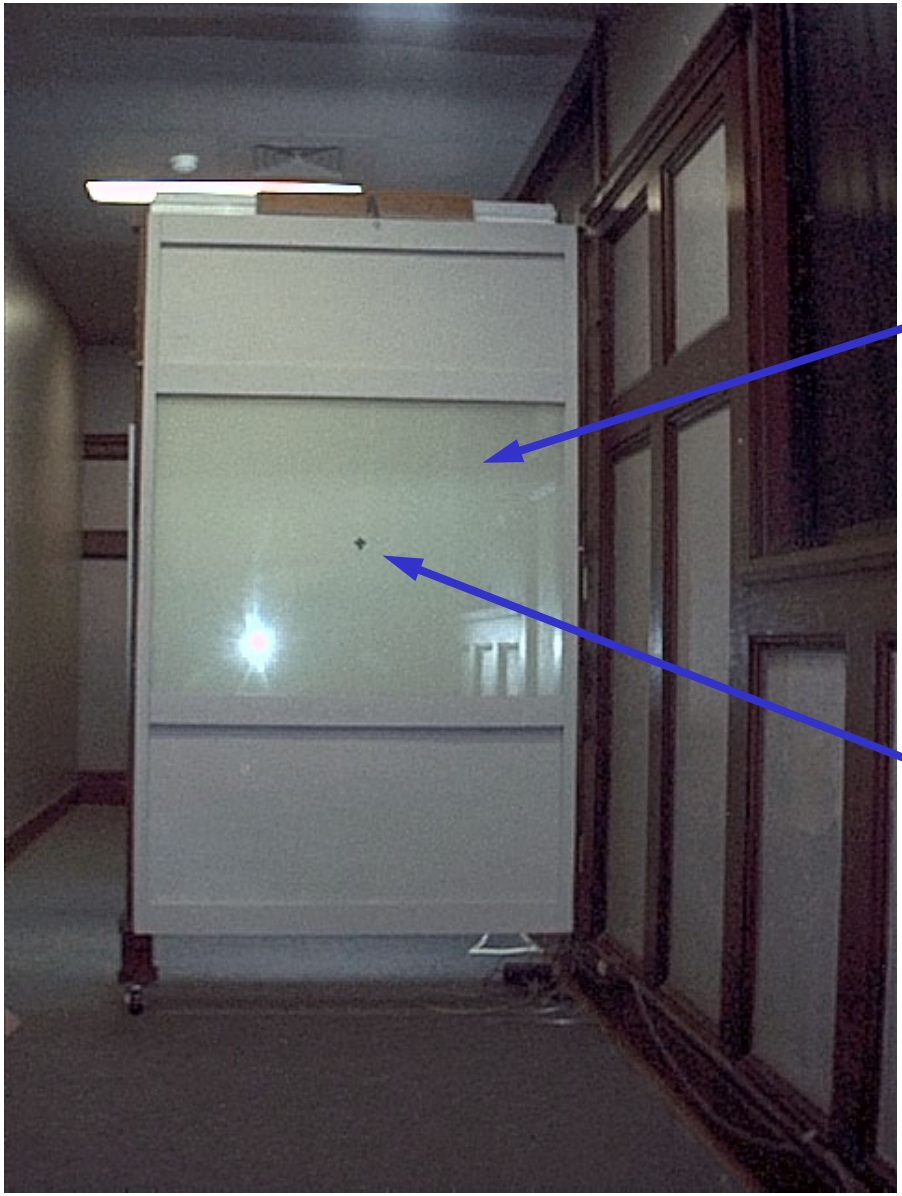
Stimulus Configuration Teleprompter

4-Position Reaction Time Response Box



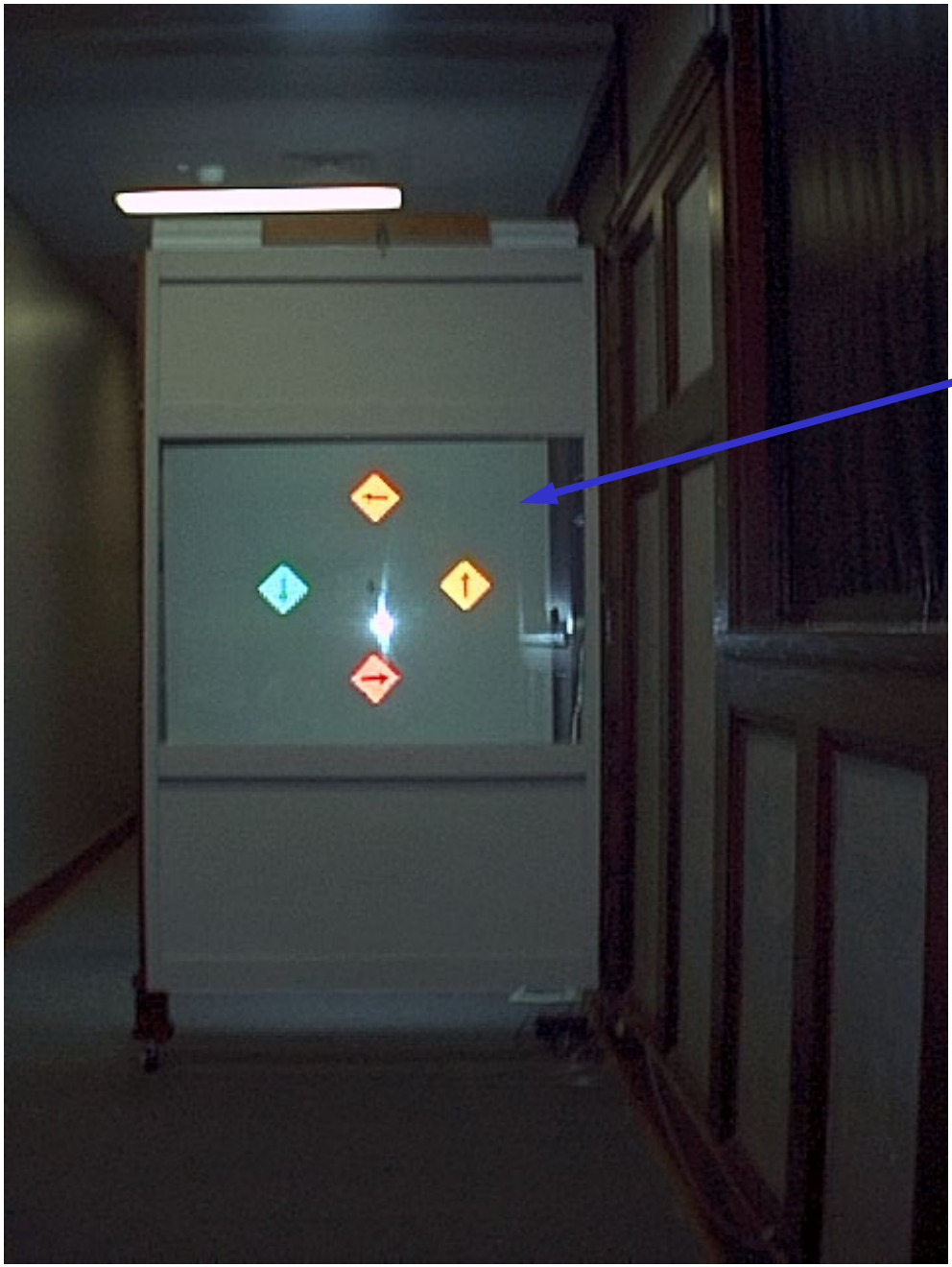
USD Vision Alley

Electrochromic Window "Shutter"



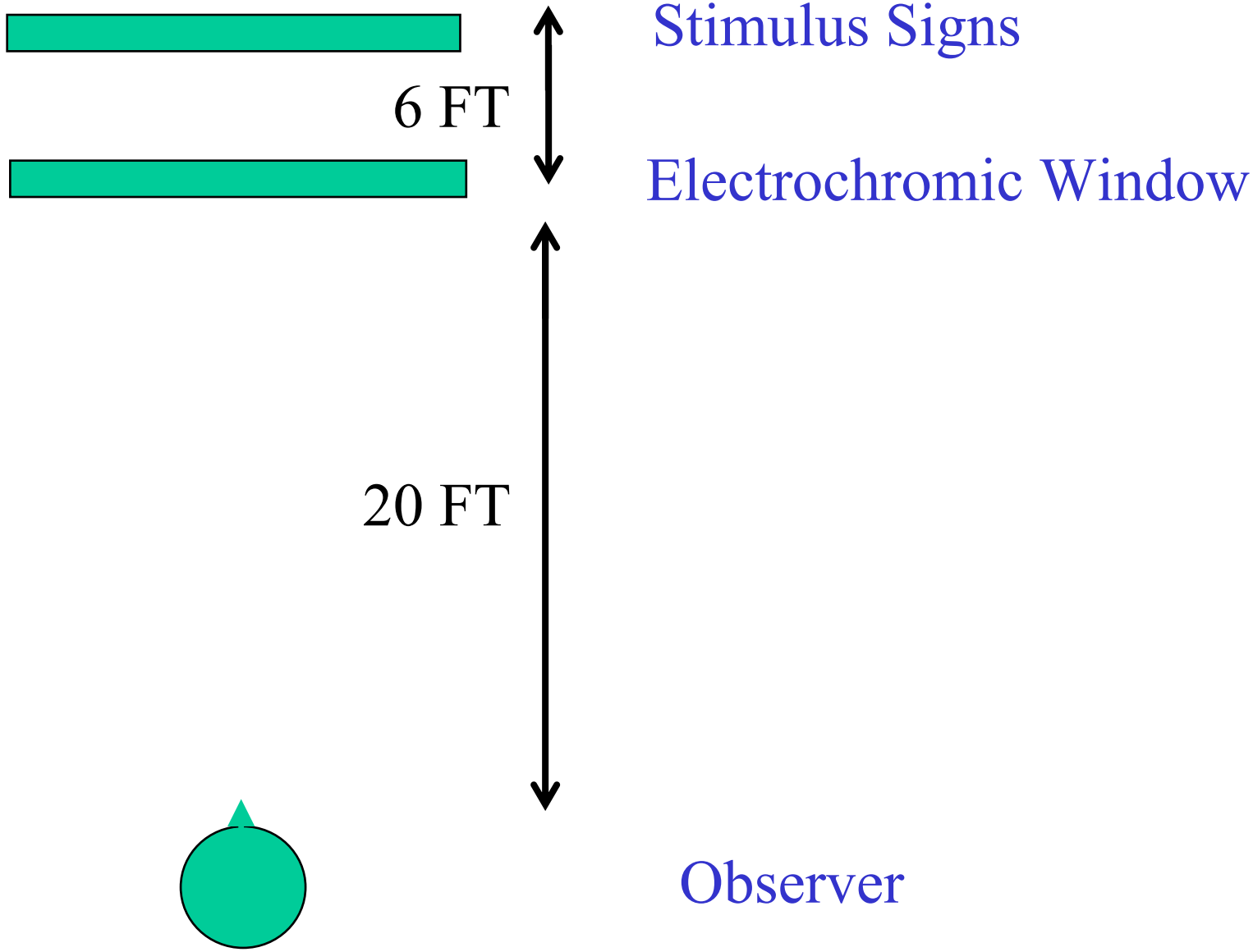
Electrochromic Window
in “opaque” state

Fixation “cross”

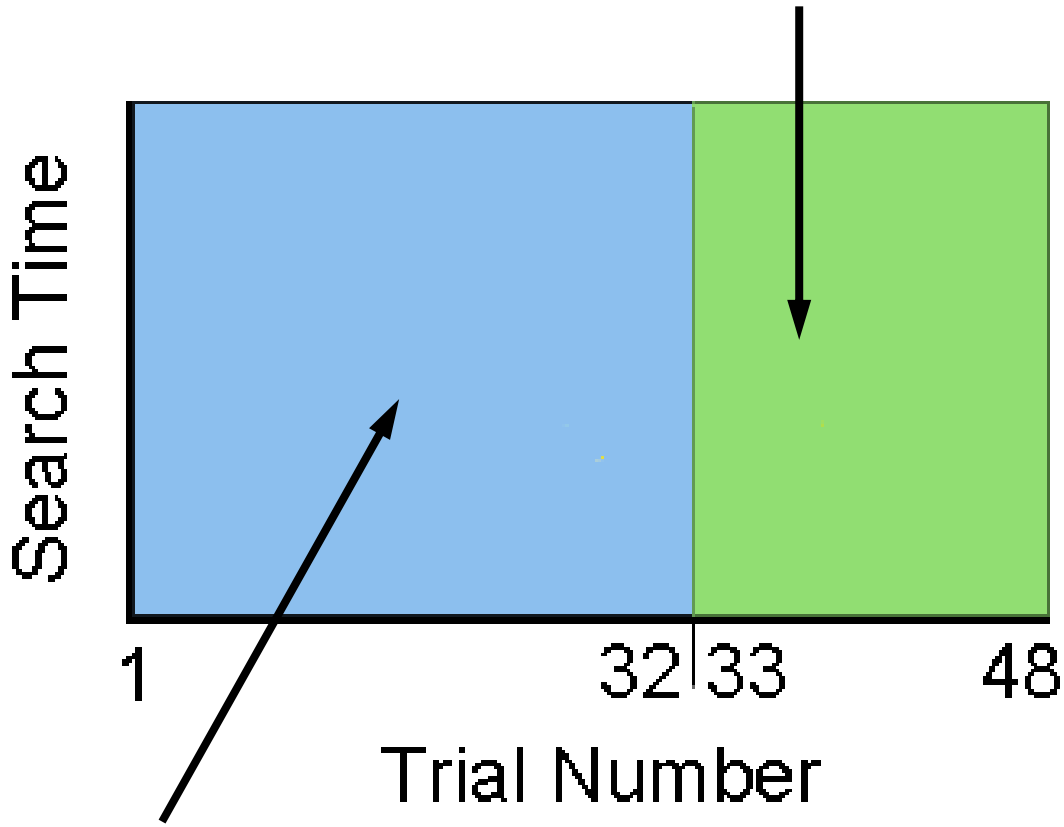


Electrochromic Window in "clear" state

Allows visual access to signs mounted on Daylight Simulation Panel


Stimulus Signs
6 FT
Electrochromic Window
20 FT
Observer

Random target position
Fluorescent YG replaces Yellow stimulus
Fluorescent YG always contains target

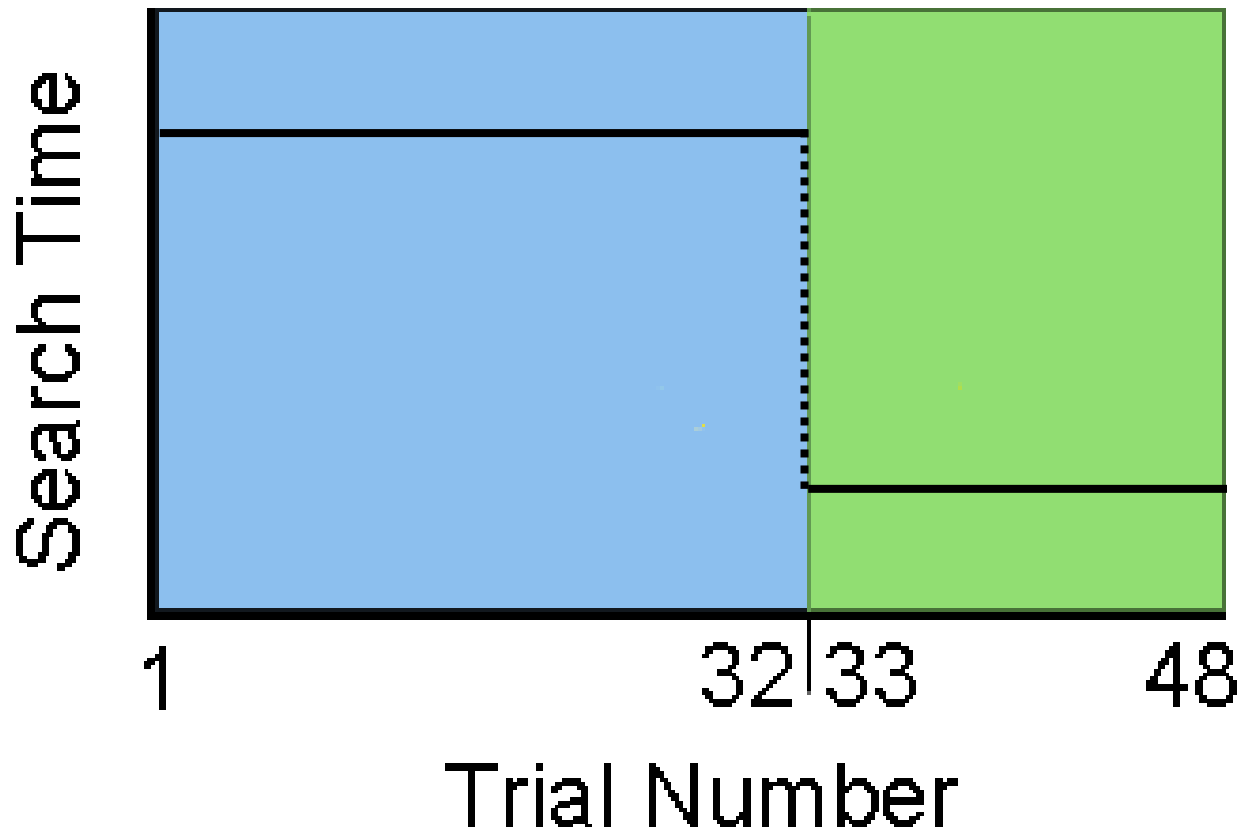


Random target position
Random target color
No fluorescent stimuli

Hypothetical Outcomes

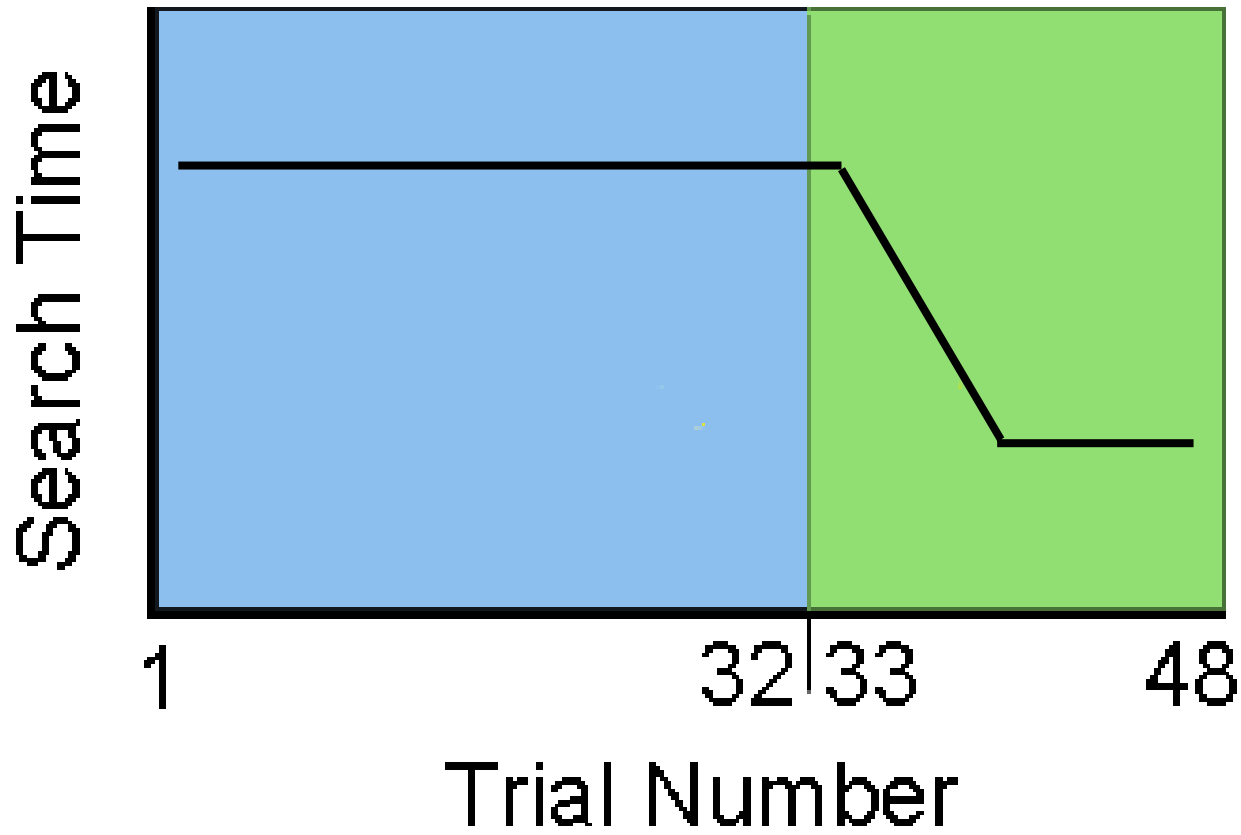
Attentional Conspicuity Signature

Immediate and significant reduction in search time between Trial 32 and Trial 33 - marking the surprise appearance of the florescent yellow-green stimulus

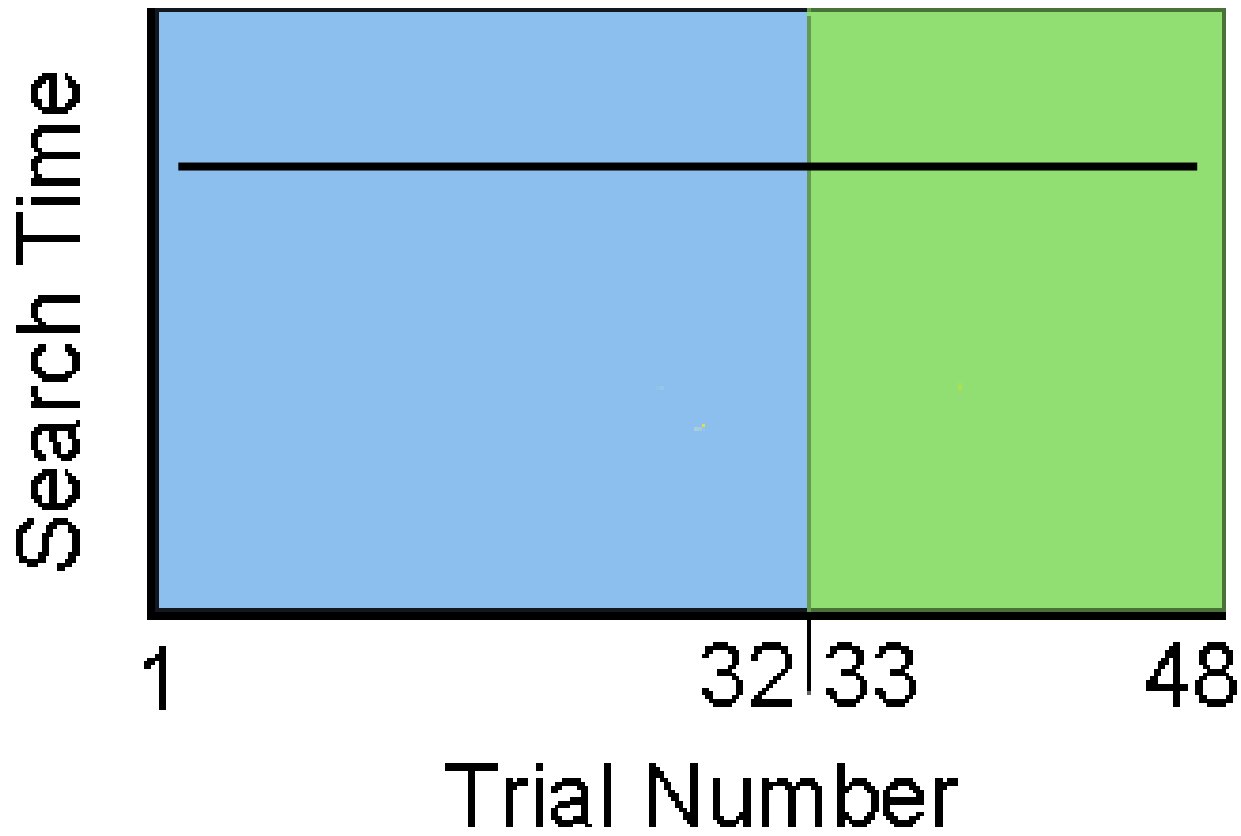


Search Conspicuity Signature

Gradual reduction in search times following Trial 33 as participants begin to realize that the target always appears on the florescent yellow-green stimulus and guide their allocation of attention accordingly.

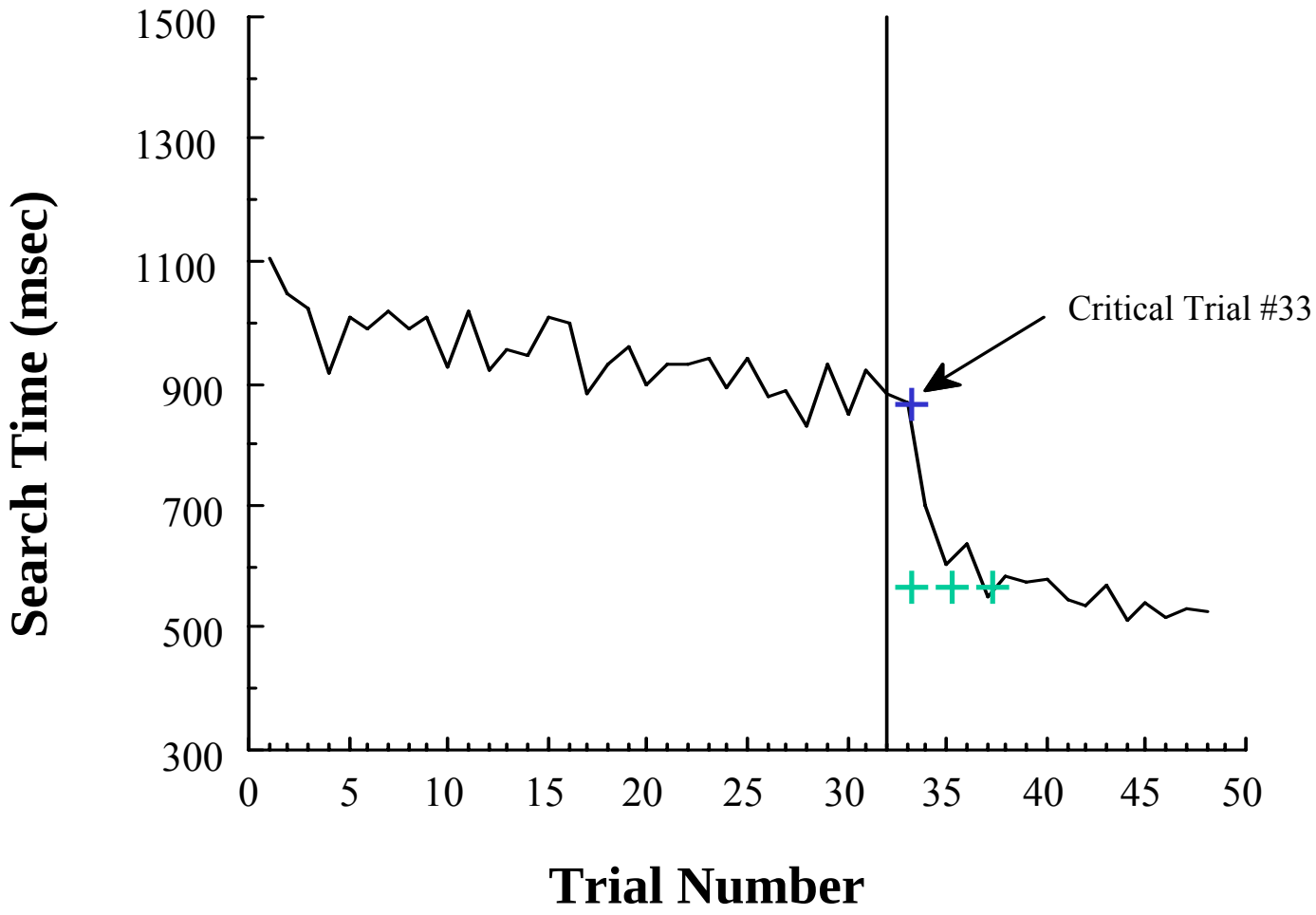


Neither Attentional nor Search Conspicuity

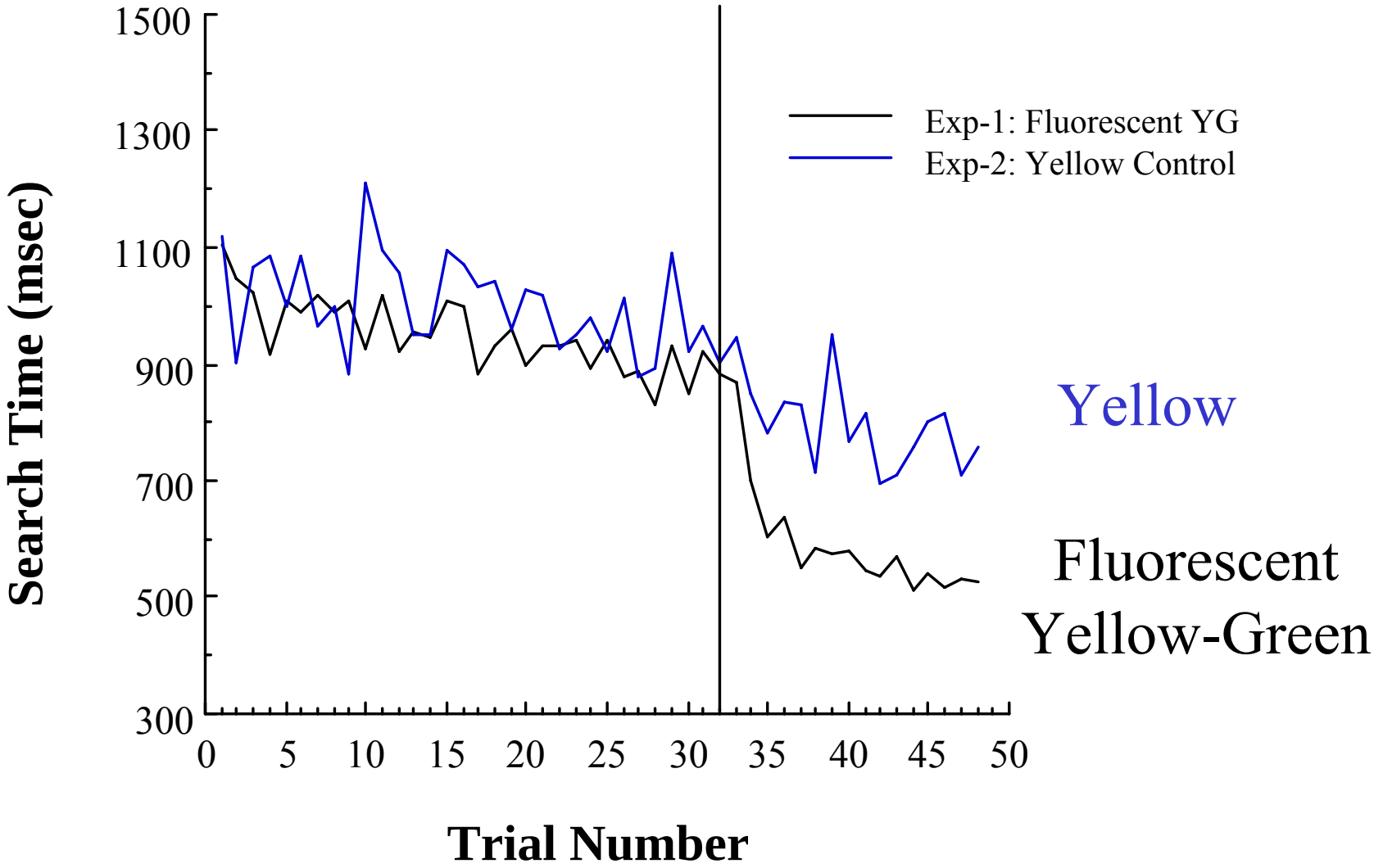


Results

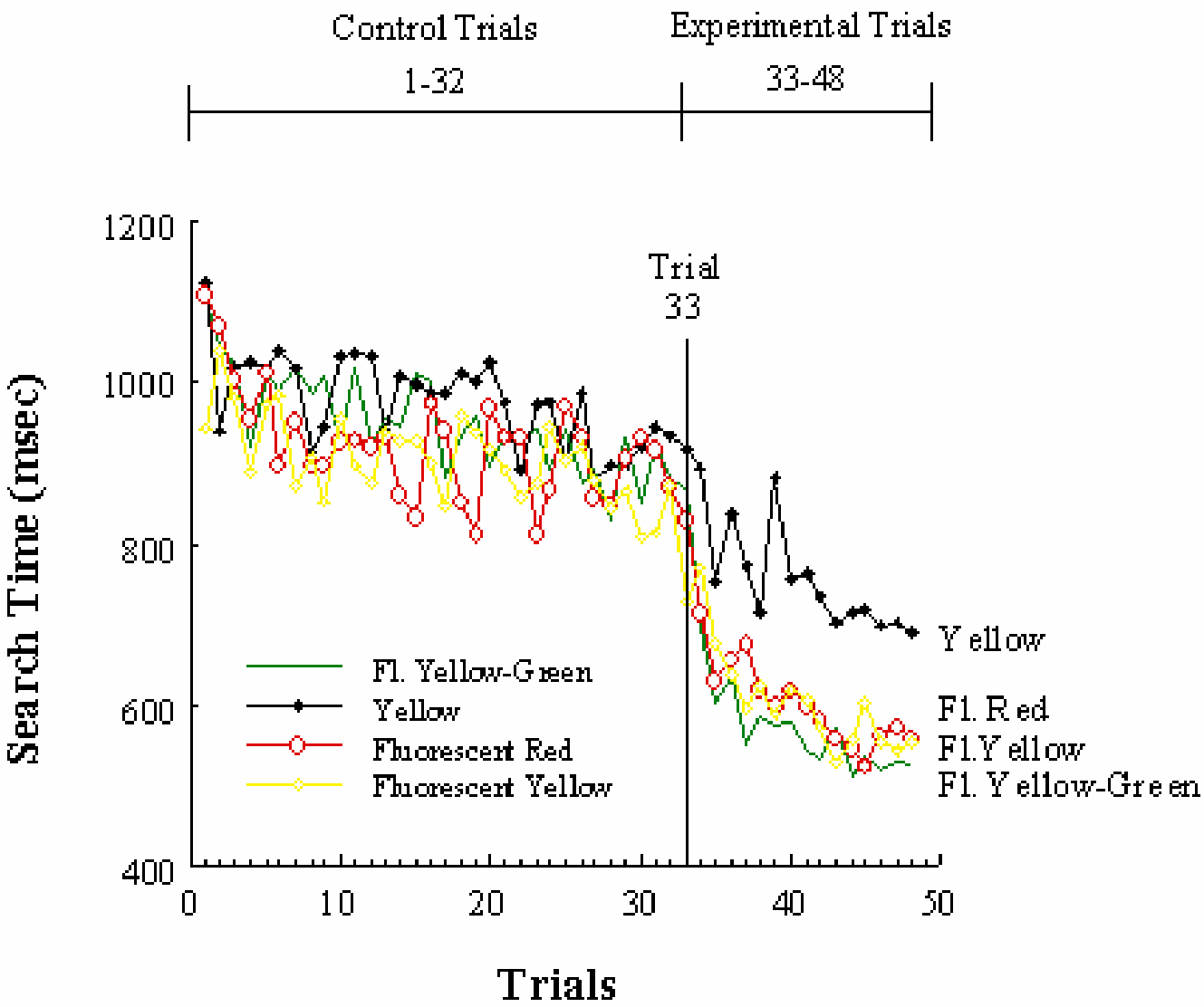
Fluorescent Yellow-Green Target Experiment #1 (N=42)



Non-Fluorescent Yellow "Control" Experiment #2 (N=20)



Experiment #3
Generalization to Other Fluorescent Colors



Preliminary Conclusions

- Unexpected introduction of fluorescent sign failed to "grab attention" on the critical stimulus trial (#33)
- No evidence of "attentional conspicuity" ("bottom-up" mechanism) despite large number of subjects
- Very strong "search conspicuity" benefit afforded by "expected" fluorescent yellow green stimulus ("top-down" mechanism)

Follow-Up Investigations

- Replication of research protocol with other fluorescent and non-fluorescent color targets
- Examination of SET SIZE EFFECTS under multicolored distractor conditions
  (Will fluorescent stimuli violate D'Zmura Law)
- Development of additional protocols for evaluating the efficacy of "bottom up" mechanisms
- Extention and validation of Color Appearance Models to the domain of fluorescent stimuli

Alternative Explanation of Results

Could observers be "suppressing" color information by the 33rd trial (since color was task irrelevant during the first 32 trials)?

Selective Attention Demo…

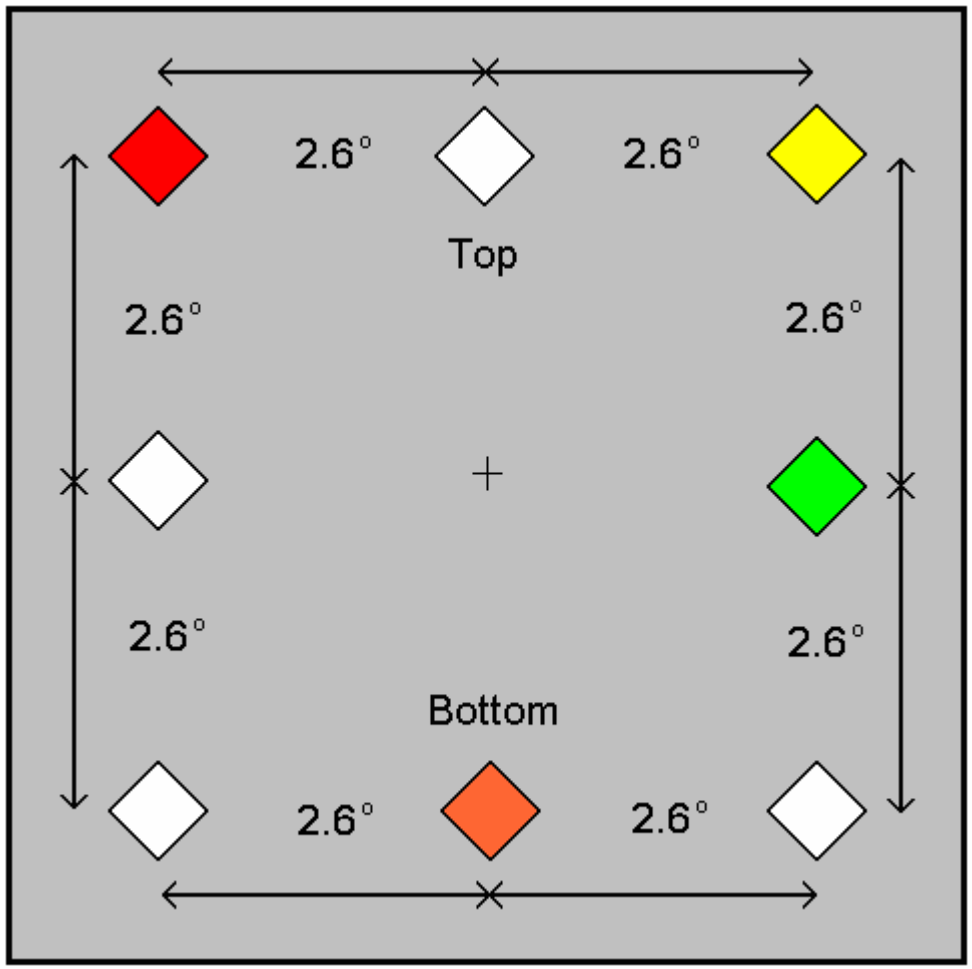
Click to start

Simple Eye Tracking Study of Bottom-Up Visual Capture

(Schieber, Willan & Schlorholtz, *in press*)

- 5 sec stimulus exposures
- Arrays of 4 stimuli of different colors (non-fluorescent)
- N = 24; 18 stimulus trials
- Unexpected "attention grabbing" stimulus on trials 9 and 18
- Fluorescent Yellow-Green versus Flashing Light Panel ("ground truth")

Stimulus Location Chart with 4 Sample Stimuli

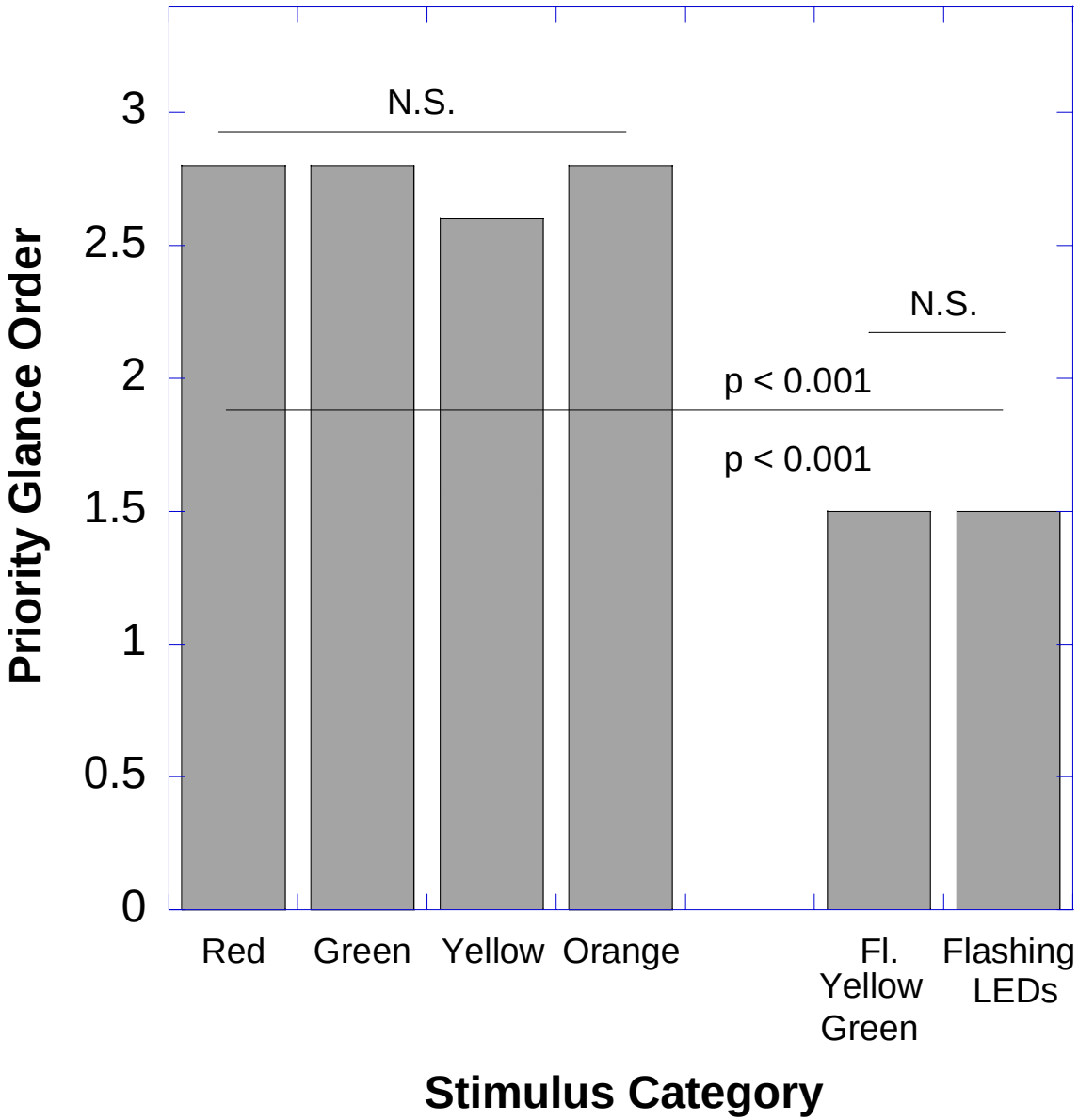


Dependent Measures and Research Questions

- Order of sequential target fixation
- Fixation duration

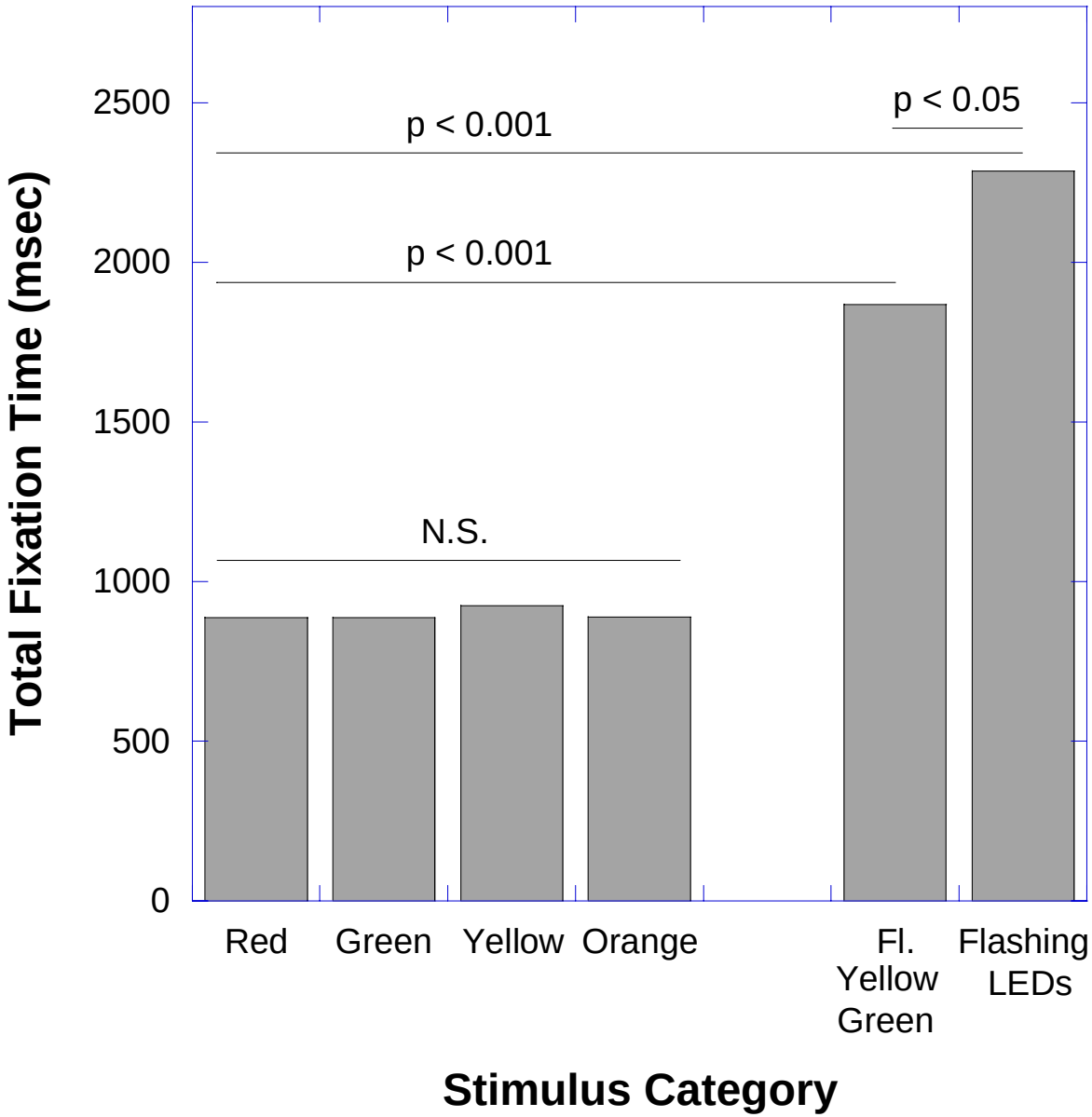
- Are observers more likely to make first fixations to Fluorescent Y-G and/or Flashing Light stimuli? (bottom-up capture)
- Do observers spend more time gazing at the experimental stimuli? (top-down capture)

Fixation Priority Results



Both the "ground truth" and the fluorescent color demonstrated bottom-up attentional capture

Total Glance Time Results



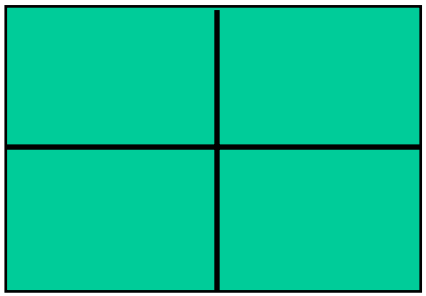
The End

(to be continued…)

Appendix

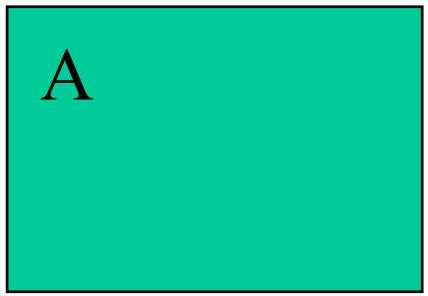
Rock Paradigm

1



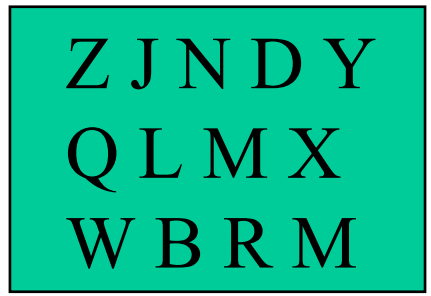
1. Fixation Cross

2



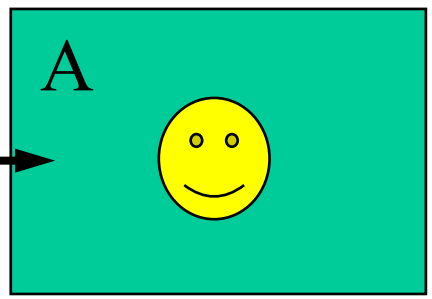
2. Briefly Presented Stimulus for Quadrant Localization

3



3. Follow-up Pattern Mask

"Odd ball" central stimulus on 8th trial



87% fail to "see" odd ball stimulus