# Testing visual performance based mesopic models

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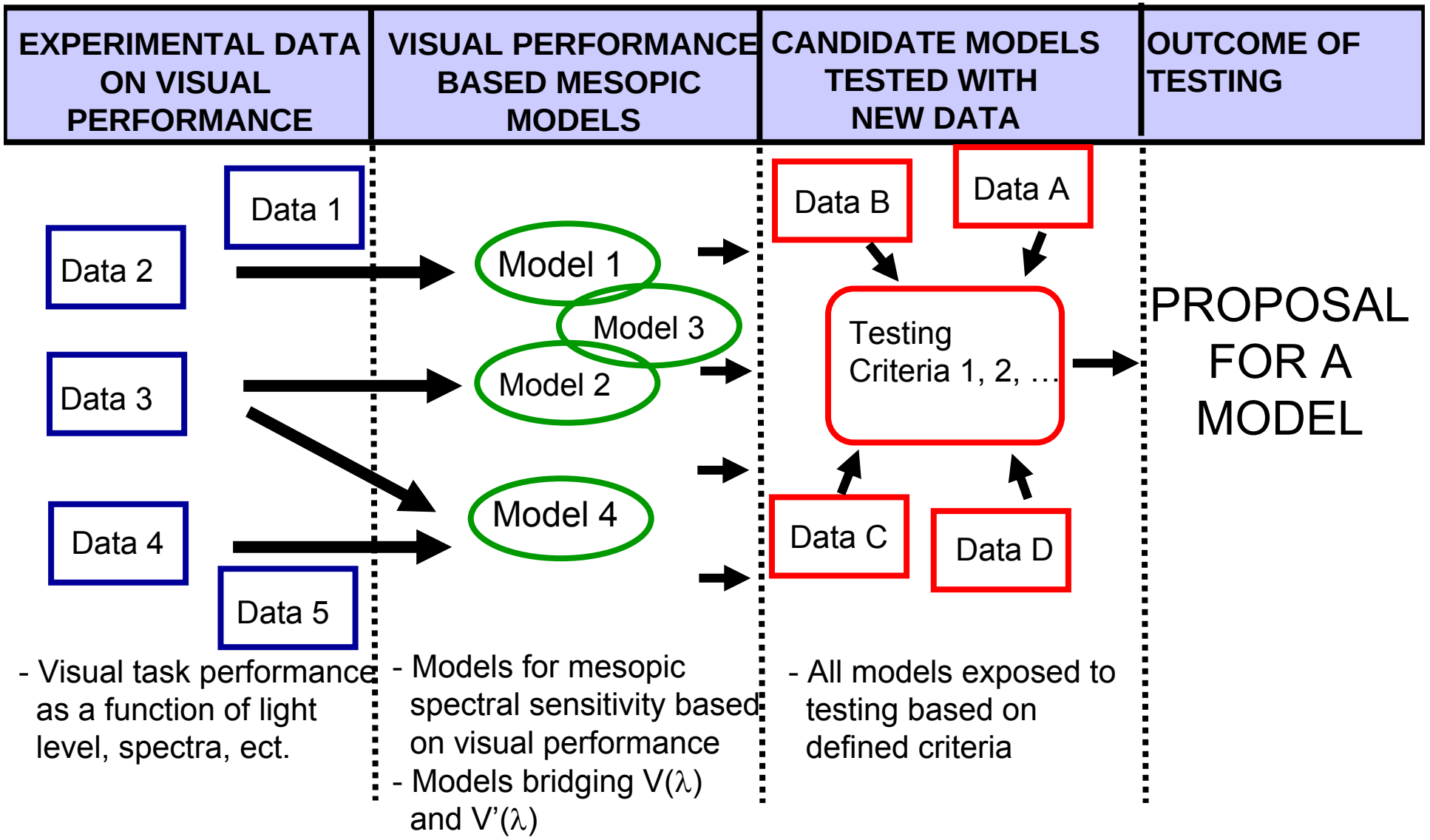
# Towards Proposal of a Model



# Criteria for Testing the Models

## Possible criteria

Criteria 1

- Spread in Mesopic Contrast for constant VP

Criteria 2

- Sensitivity analysis

Criteria 3

- ?

# Visual performance based mesopic models

Constraints on the model:

- It must be additive
- It must tend to $V(\lambda)$ at the upper end of the mesopic region and to $V'(\lambda)$ a the lower end

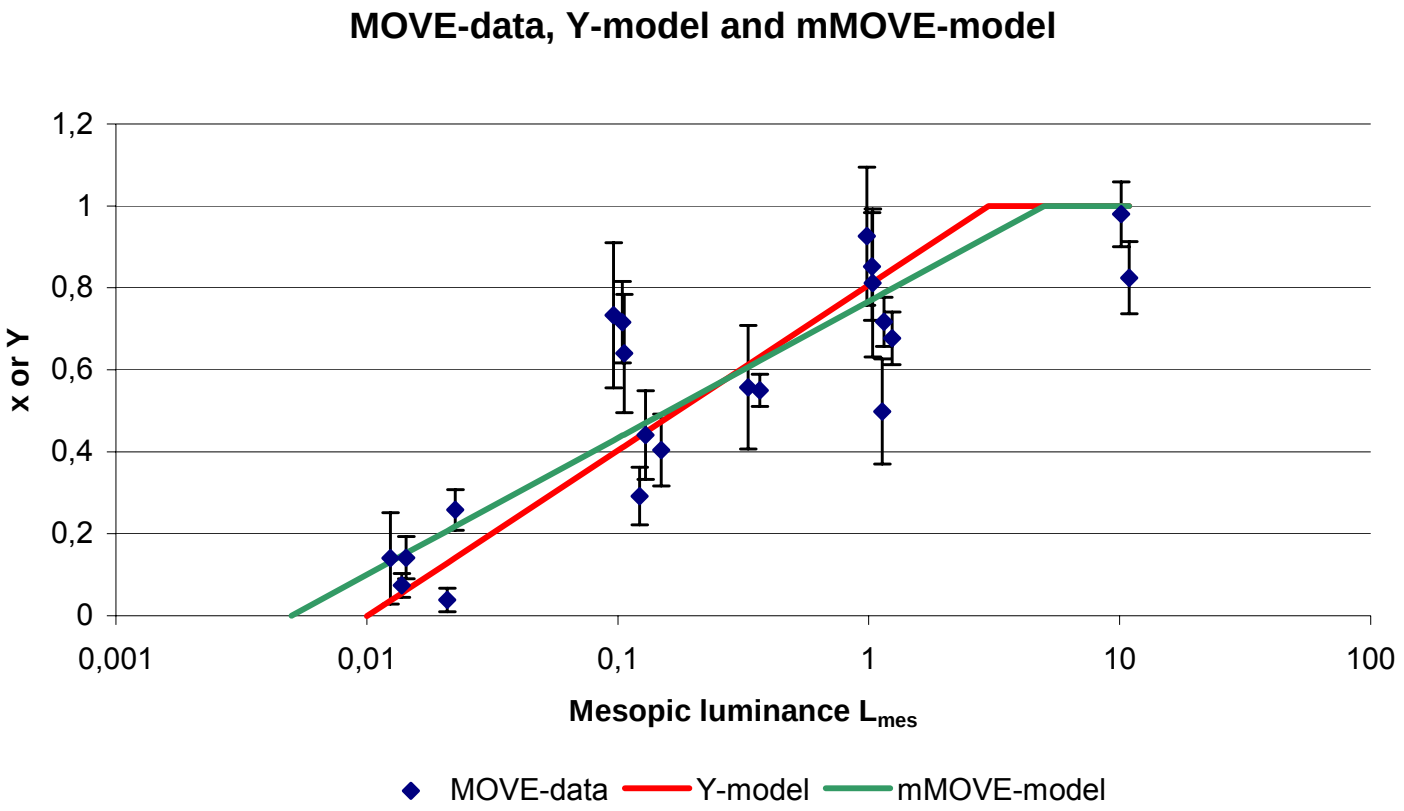
The practical model of mesopic photometry takes the form:

$$V_{mes}(\lambda) = x\, V(\lambda) + (1 - x)\, V'(\lambda)$$

Possible candidate models

- X-model
- MOVE-model
- Y-model
- Modified MOVE-model

# Modified MOVE model

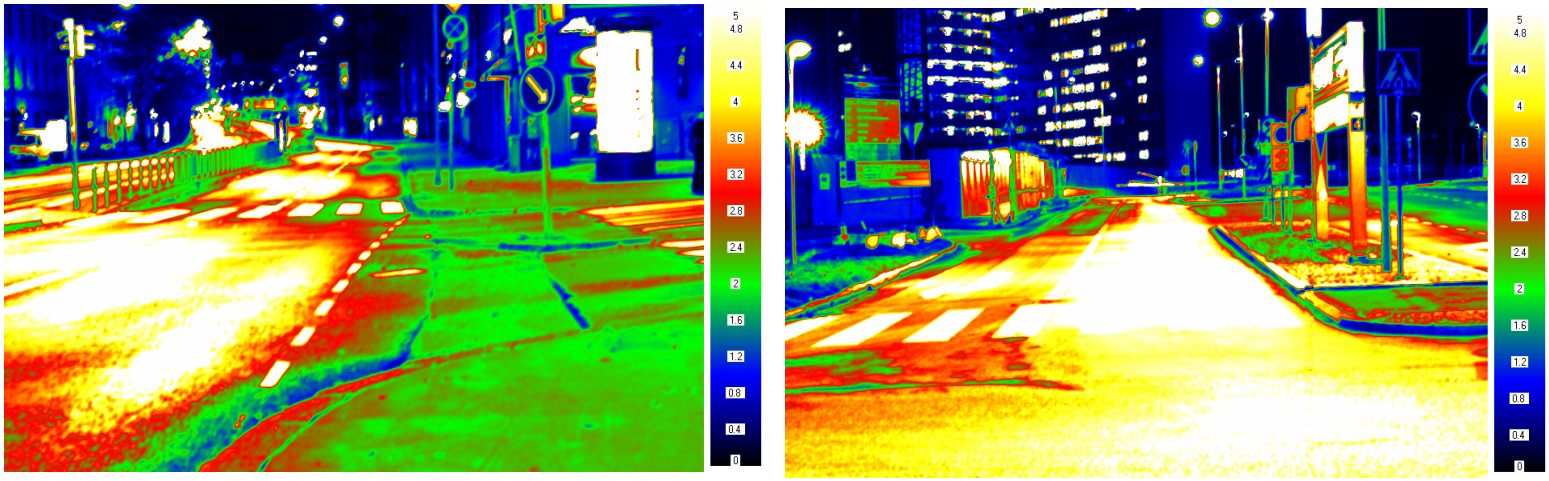



$$M(x)V_{mes}(\lambda) = xV(\lambda) + (1-x)V'(\lambda) \qquad \text{for } 0 \le x \le 1$$

# Modified MOVE – criteria for upper limit

## 1. To cover luminances encountered in actual driving conditions

- present recommendations for road surface luminances
  0.3 – 1.2 cd/m$^2$ (IESNA), 0.5 – 2 cd/m$^2$ (CEN)
- especially in urban areas the surrounding areas of road increase adaptation luminance and also the road surface luminances well above 2 cd/m$^2$
- varying weather conditions induce visual field luminances well above 2 cd/m$^2$




## 2. To accomodate for the decreased differences between MOVE model and V(λ) above 5 cd/m$^2$

(luminance differences less than 5% for light sources with S/P=0.5…2.5)

# Modified MOVE model

**a**

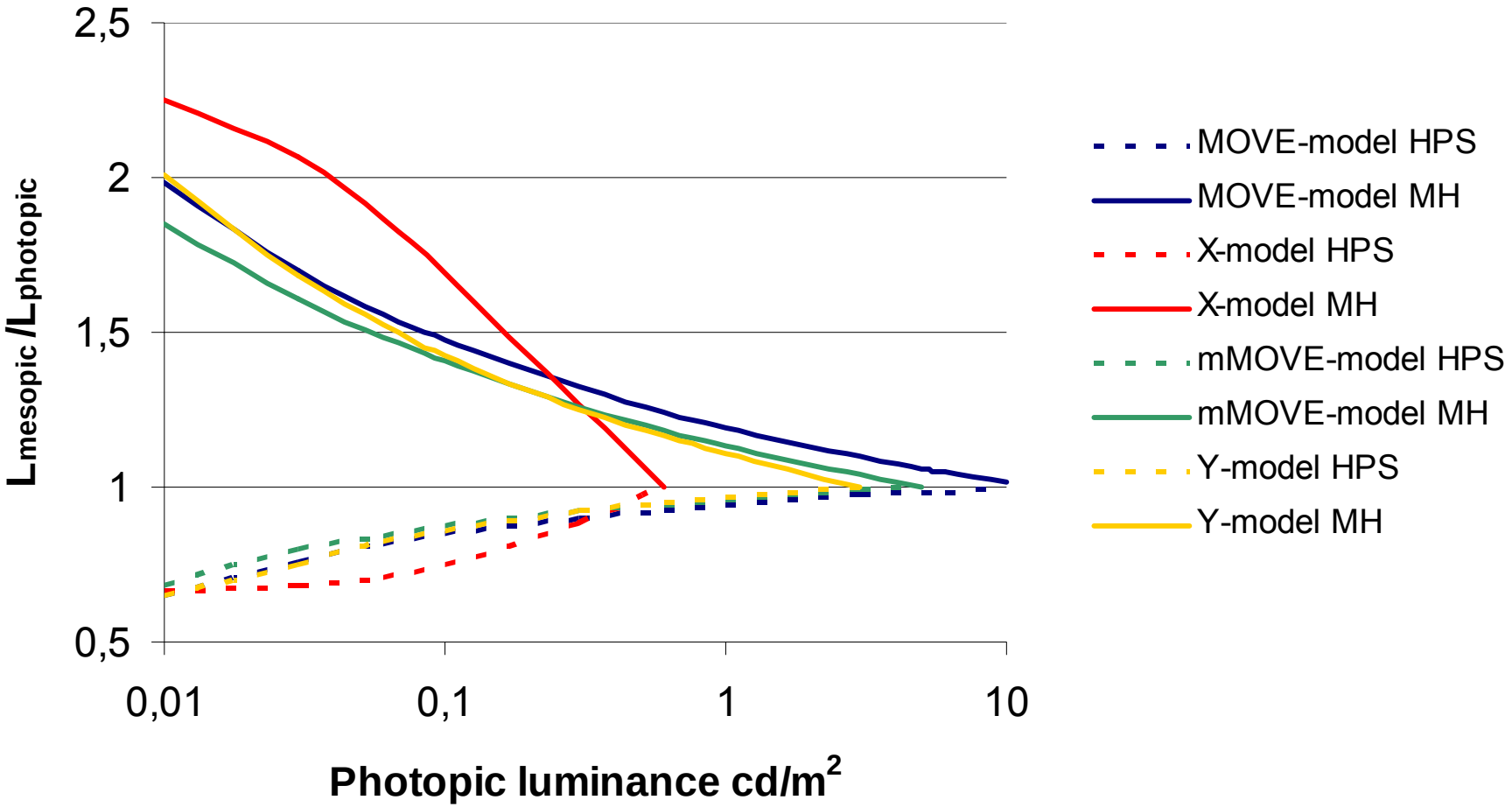
| *x* | Photopic luminance cd/m$^2$ | | | | | | |
|---|---|---|---|---|---|---|---|
| **S/P** | **0.01** | **0.03** | **0.1** | **0.3** | **1** | **3** | **4.5** |
| **0.25** | | 0.1542 | 0.3830 | 0.5644 | 0.7538 | 0.9225 | 0.9841 |
| **0.35** | | 0.1804 | 0.3920 | 0.5688 | 0.7558 | 0.9230 | 0.9842 |
| **0.45** | 0.0000 | 0.1992 | 0.4000 | 0.5730 | 0.7576 | 0.9235 | 0.9843 |
| **0.55** | 0.0190 | 0.2140 | 0.4073 | 0.5770 | 0.7594 | 0.9240 | 0.9844 |
| **0.65** | 0.0459 | 0.2265 | 0.4139 | 0.5808 | 0.7612 | 0.9245 | 0.9845 |
| **0.75** | 0.0655 | 0.2373 | 0.4201 | 0.5844 | 0.7629 | 0.9249 | 0.9846 |
| **0.85** | 0.0812 | 0.2468 | 0.4258 | 0.5878 | 0.7646 | 0.9254 | 0.9846 |
| **0.95** | 0.0943 | 0.2553 | 0.4311 | 0.5911 | 0.7662 | 0.9258 | 0.9847 |
| **1.05** | 0.1057 | 0.2631 | 0.4361 | 0.5942 | 0.7678 | 0.9263 | 0.9848 |
| **1.15** | 0.1157 | 0.2702 | 0.4408 | 0.5972 | 0.7693 | 0.9267 | 0.9849 |
| **1.25** | 0.1247 | 0.2767 | 0.4452 | 0.6001 | 0.7708 | 0.9272 | 0.9850 |
| **1.35** | 0.1329 | 0.2828 | 0.4494 | 0.6029 | 0.7723 | 0.9276 | 0.9851 |
| **1.45** | 0.1404 | 0.2885 | 0.4534 | 0.6056 | 0.7737 | 0.9280 | 0.9852 |
| **1.55** | 0.1473 | 0.2939 | 0.4573 | 0.6082 | 0.7751 | 0.9284 | 0.9853 |
| **1.65** | 0.1538 | 0.2990 | 0.4609 | 0.6107 | 0.7764 | 0.9289 | 0.9853 |
| **1.75** | 0.1598 | 0.3038 | 0.4645 | 0.6131 | 0.7778 | 0.9293 | 0.9854 |
| **1.85** | 0.1654 | 0.3083 | 0.4678 | 0.6155 | 0.7791 | 0.9297 | 0.9855 |
| **1.95** | 0.1708 | 0.3126 | 0.4711 | 0.6178 | 0.7803 | 0.9301 | 0.9856 |
| **2.05** | 0.1758 | 0.3168 | 0.4742 | 0.6200 | 0.7816 | 0.9304 | 0.9857 |
| **2.15** | 0.1806 | 0.3207 | 0.4772 | 0.6221 | 0.7828 | 0.9308 | 0.9857 |
| **2.25** | 0.1852 | 0.3245 | 0.4801 | 0.6242 | 0.7840 | 0.9312 | 0.9858 |
| **2.35** | 0.1895 | 0.3282 | 0.4830 | 0.6263 | 0.7852 | 0.9316 | 0.9859 |
| **2.45** | 0.1937 | 0.3317 | 0.4857 | 0.6283 | 0.7863 | 0.9319 | 0.9860 |
| **2.55** | 0.1977 | 0.3351 | 0.4883 | 0.6302 | 0.7875 | 0.9323 | 0.9860 |
| **2.65** | 0.2015 | 0.3383 | 0.4909 | 0.6321 | 0.7886 | 0.9327 | 0.9861 |
| **2.75** | 0.2052 | 0.3415 | 0.4934 | 0.6339 | 0.7896 | 0.9330 | 0.9862 |

**b**

| $L_{mes}$ | Photopic luminance cd/m$^2$ | | | | | | |
|---|---|---|---|---|---|---|---|
| **S/P** | **0.01** | **0.03** | **0.1** | **0.3** | **1** | **3** | **4.5** |
| **0.25** | 0.0025 | 0.0145 | 0.0705 | 0.2467 | 0.9130 | 2.9265 | 4.4782 |
| **0.35** | 0.0035 | 0.0174 | 0.0750 | 0.2545 | 0.9253 | 2.9367 | 4.4812 |
| **0.45** | 0.0045 | 0.0198 | 0.0793 | 0.2620 | 0.9373 | 2.9468 | 4.4842 |
| **0.55** | 0.0057 | 0.0220 | 0.0834 | 0.2693 | 0.9492 | 2.9568 | 4.4872 |
| **0.65** | 0.0069 | 0.0239 | 0.0873 | 0.2764 | 0.9608 | 2.9666 | 4.4901 |
| **0.75** | 0.0079 | 0.0258 | 0.0911 | 0.2833 | 0.9722 | 2.9763 | 4.4929 |
| **0.85** | 0.0088 | 0.0275 | 0.0947 | 0.2901 | 0.9835 | 2.9859 | 4.4958 |
| **0.95** | 0.0096 | 0.0292 | 0.0983 | 0.2967 | 0.9945 | 2.9953 | 4.4986 |
| **1.05** | 0.0104 | 0.0308 | 0.1017 | 0.3032 | 1.0054 | 3.0046 | 4.5014 |
| **1.15** | 0.0111 | 0.0323 | 0.1051 | 0.3096 | 1.0161 | 3.0139 | 4.5041 |
| **1.25** | 0.0118 | 0.0338 | 0.1083 | 0.3158 | 1.0267 | 3.0230 | 4.5068 |
| **1.35** | 0.0125 | 0.0353 | 0.1115 | 0.3220 | 1.0371 | 3.0319 | 4.5095 |
| **1.45** | 0.0132 | 0.0367 | 0.1147 | 0.3280 | 1.0473 | 3.0408 | 4.5122 |
| **1.55** | 0.0138 | 0.0381 | 0.1178 | 0.3339 | 1.0575 | 3.0496 | 4.5148 |
| **1.65** | 0.0145 | 0.0395 | 0.1208 | 0.3398 | 1.0674 | 3.0582 | 4.5174 |
| **1.75** | 0.0151 | 0.0408 | 0.1238 | 0.3455 | 1.0773 | 3.0668 | 4.5200 |
| **1.85** | 0.0157 | 0.0421 | 0.1267 | 0.3512 | 1.0870 | 3.0753 | 4.5225 |
| **1.95** | 0.0163 | 0.0434 | 0.1295 | 0.3568 | 1.0966 | 3.0836 | 4.5250 |
| **2.05** | 0.0169 | 0.0446 | 0.1324 | 0.3623 | 1.1060 | 3.0919 | 4.5275 |
| **2.15** | 0.0174 | 0.0459 | 0.1352 | 0.3677 | 1.1154 | 3.1001 | 4.5299 |
| **2.25** | 0.0180 | 0.0471 | 0.1379 | 0.3731 | 1.1246 | 3.1082 | 4.5323 |
| **2.35** | 0.0185 | 0.0483 | 0.1406 | 0.3784 | 1.1338 | 3.1162 | 4.5347 |
| **2.45** | 0.0191 | 0.0495 | 0.1433 | 0.3836 | 1.1428 | 3.1241 | 4.5371 |
| **2.55** | 0.0196 | 0.0506 | 0.1459 | 0.3888 | 1.1517 | 3.1319 | 4.5395 |
| **2.65** | 0.0201 | 0.0518 | 0.1485 | 0.3939 | 1.1605 | 3.1396 | 4.5418 |
| **2.75** | 0.0207 | 0.0529 | 0.1511 | 0.3989 | 1.1693 | 3.1473 | 4.5441 |

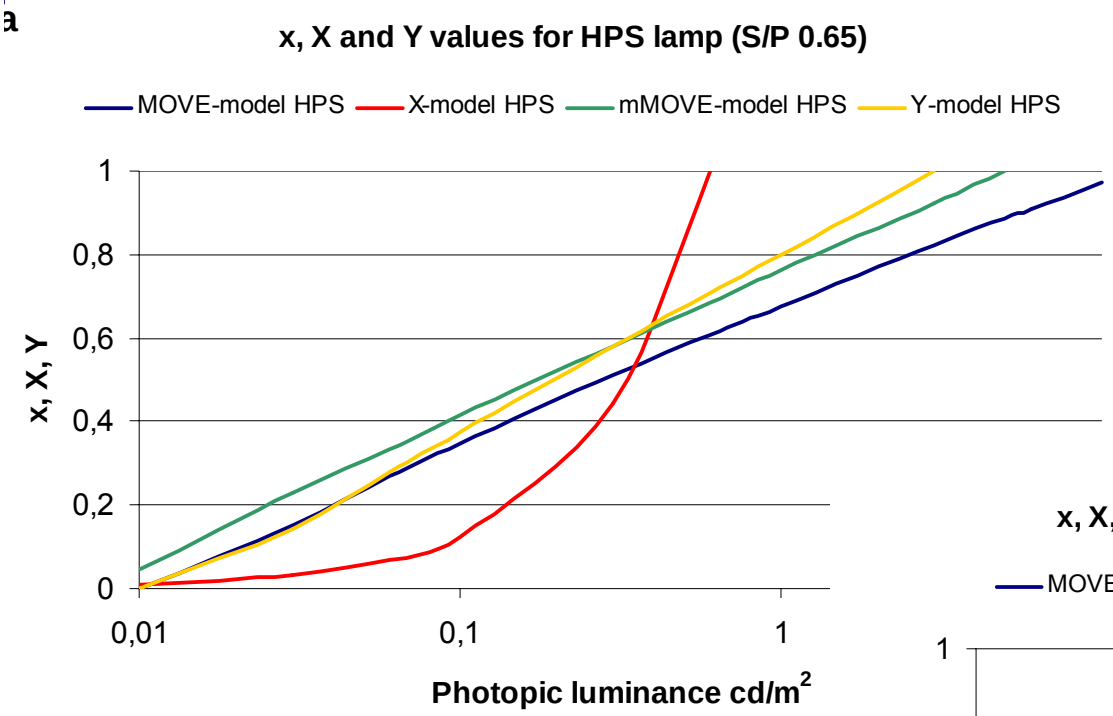
# General Comparison of Models

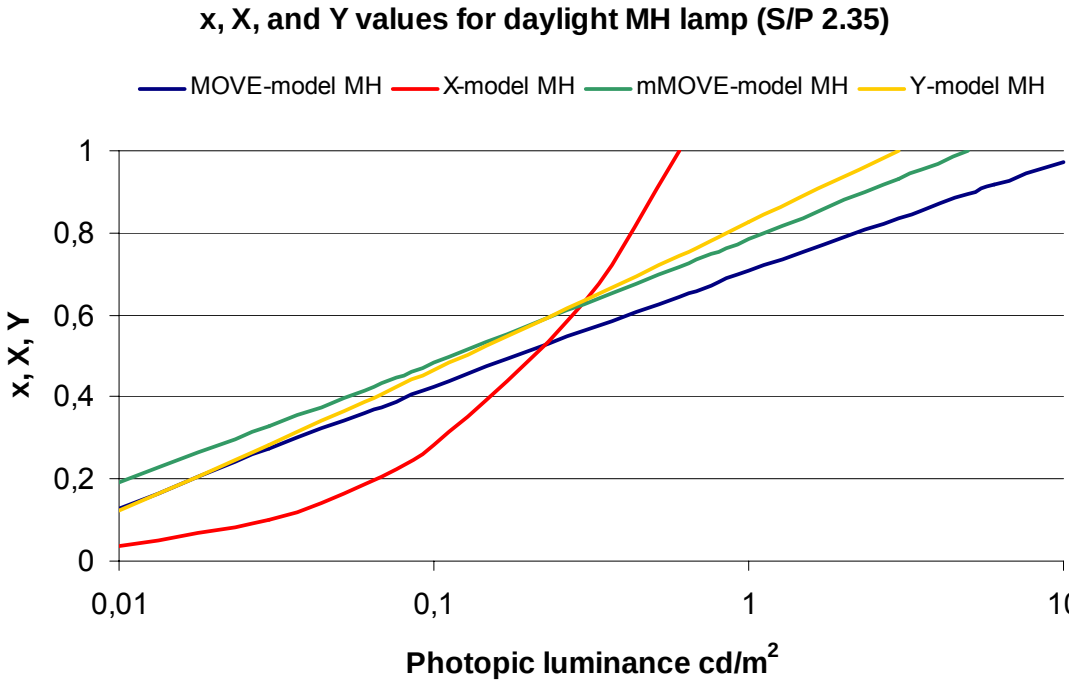
**$L_{mes}$ / $L_p$ for HPS (S/P 0.65) and daylight MH (S/P 2.35) lamps**



# General comparison of models

a



# Testing the Mesopic Models

Models

- X
- MOVE
- Y
- modified MOVE

Data sources

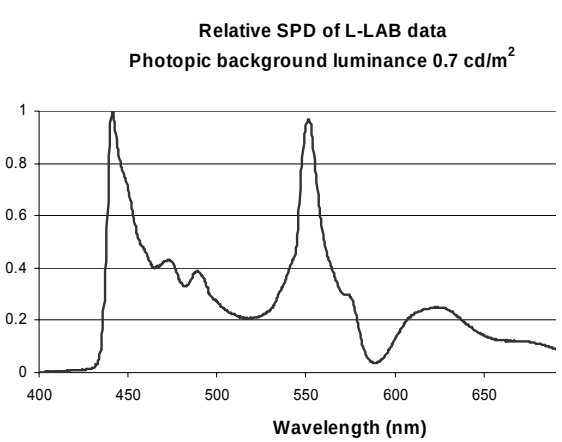
- Detection threshold data, L-LAB
- Detection threshold data, UP
- Reaction time data, TKK

Criteria

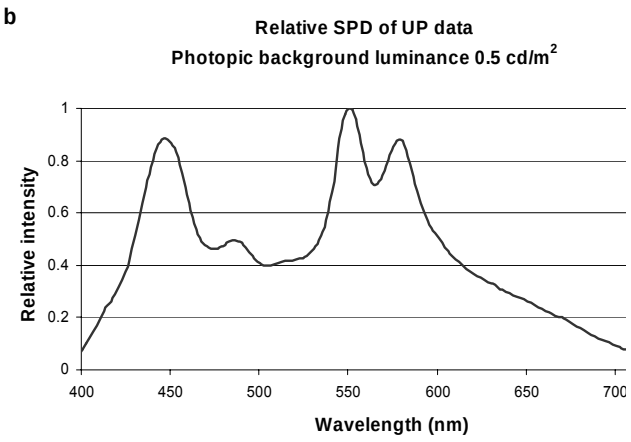
- Spread of calculated mesopic contrasts within each luminance level and eccentricity

# Data sources

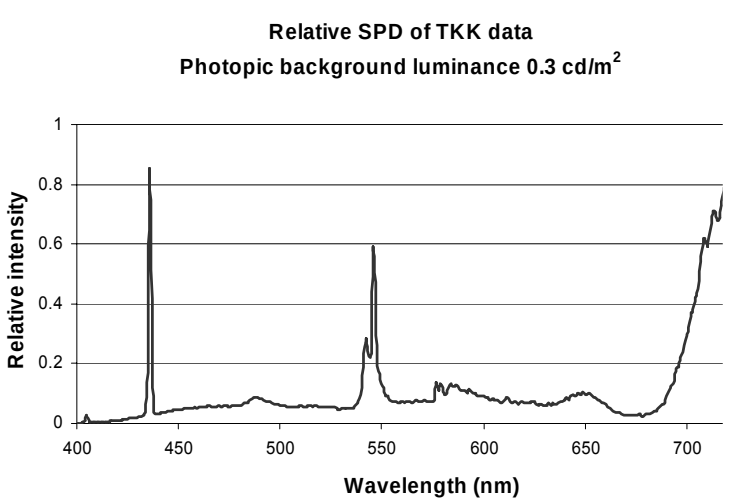
| | L-LAB | UP | TKK |
|---|---|---|---|
| **Method** | Detection threshold | Detection threshold | Reaction time |
| **Background luminance** | 0.01, 0.07, 0.7, 8 cd/m$^2$ | 0.5 cd/m$^2$ | 0.1, 0.3, 1, 3, 10 cd/m$^2$ |
| **Background color** | Uniform grey, S/P ? 2.8 | White, S/P ? 2.05 | White, S/P ? 1.86 |
| **Target eccentricity** | 2°, 6°, 10°, 14° | 20° | 10° |
| **Target colors** | blue, green, grey, red | 410 to 680 nm, 10 nm steps | blue, cyan, green, amber, red |
| **Target size** | 0.7° | 2° | 0.29° |
| **Subjects** | 40 | 1 (4 repetitions) | 5 |




b




c



# Criteria: Spread in Mesopic Contrast for constant VP

- Detection threshold experiment: target intensity increased/decreased until the target becomes visible/invisible.

  Fixed reaction time experiment: target intensity adjusted to elicit fixed reaction time.
- Mesopic contrast can be calculated with any given candidate mesopic model

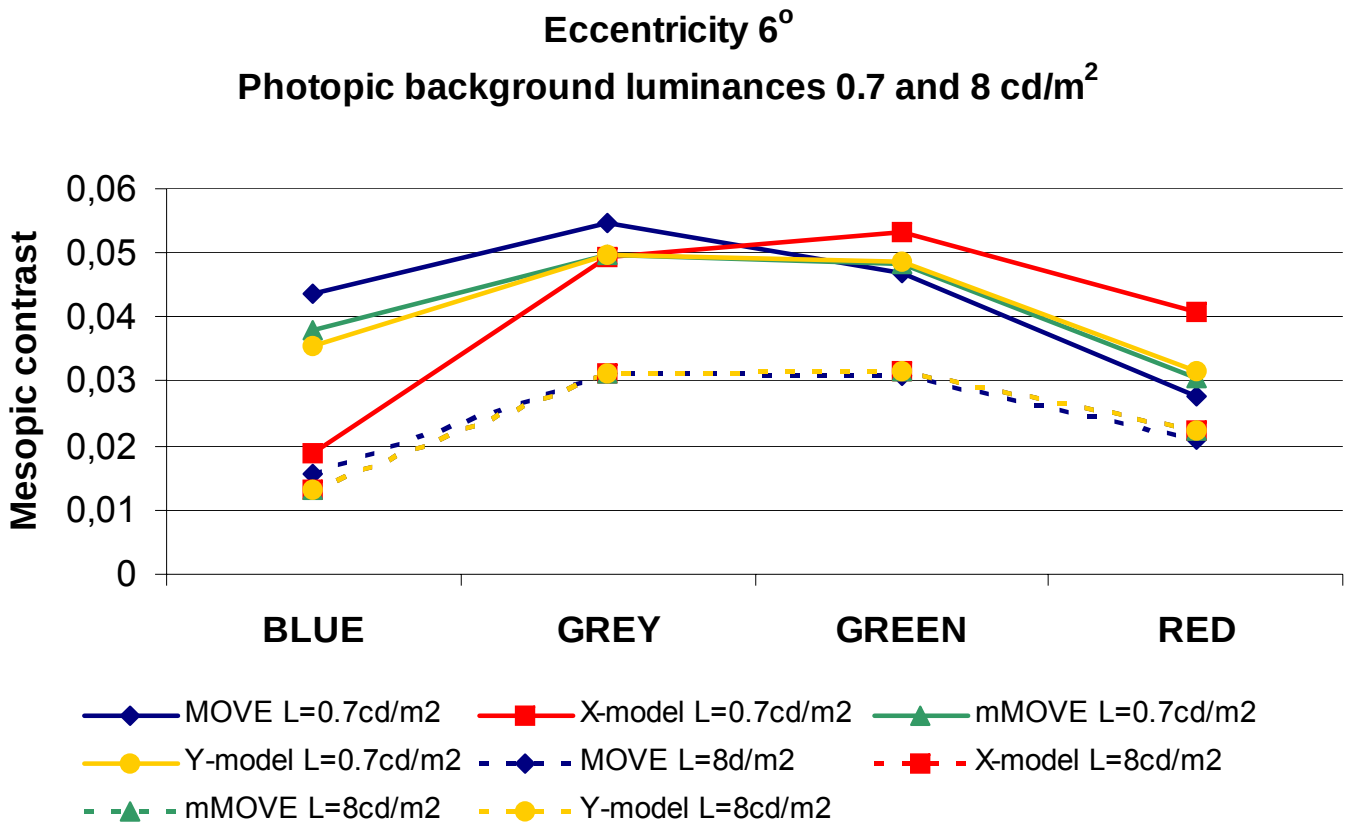
$$C_{mes} = \frac{L_{mes,t} - L_{mes,bg}}{L_{mes,bg}}$$

- Assuming that (for specific background conditions and eccentricity) the $C_{mes}$ required to reach the detection threshold/ fixed reaction time is the same for all target colors, then the spectral sensitivity function (i.e. mesopic model) describes visual performance correctly

- Optimal model is such that variation in the mesopic contrasts is minimal

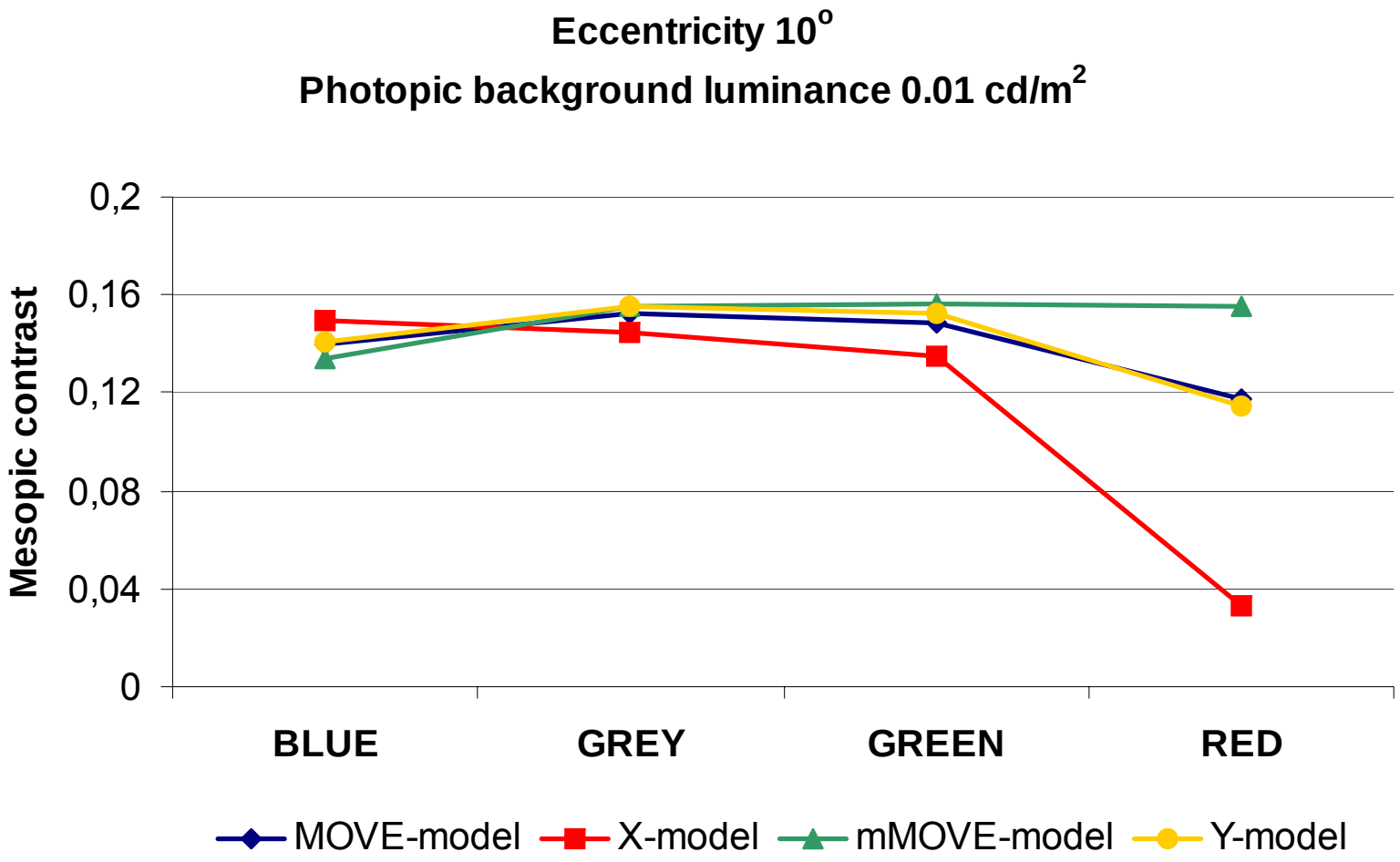
# L-LAB Detection threshold data

**b**

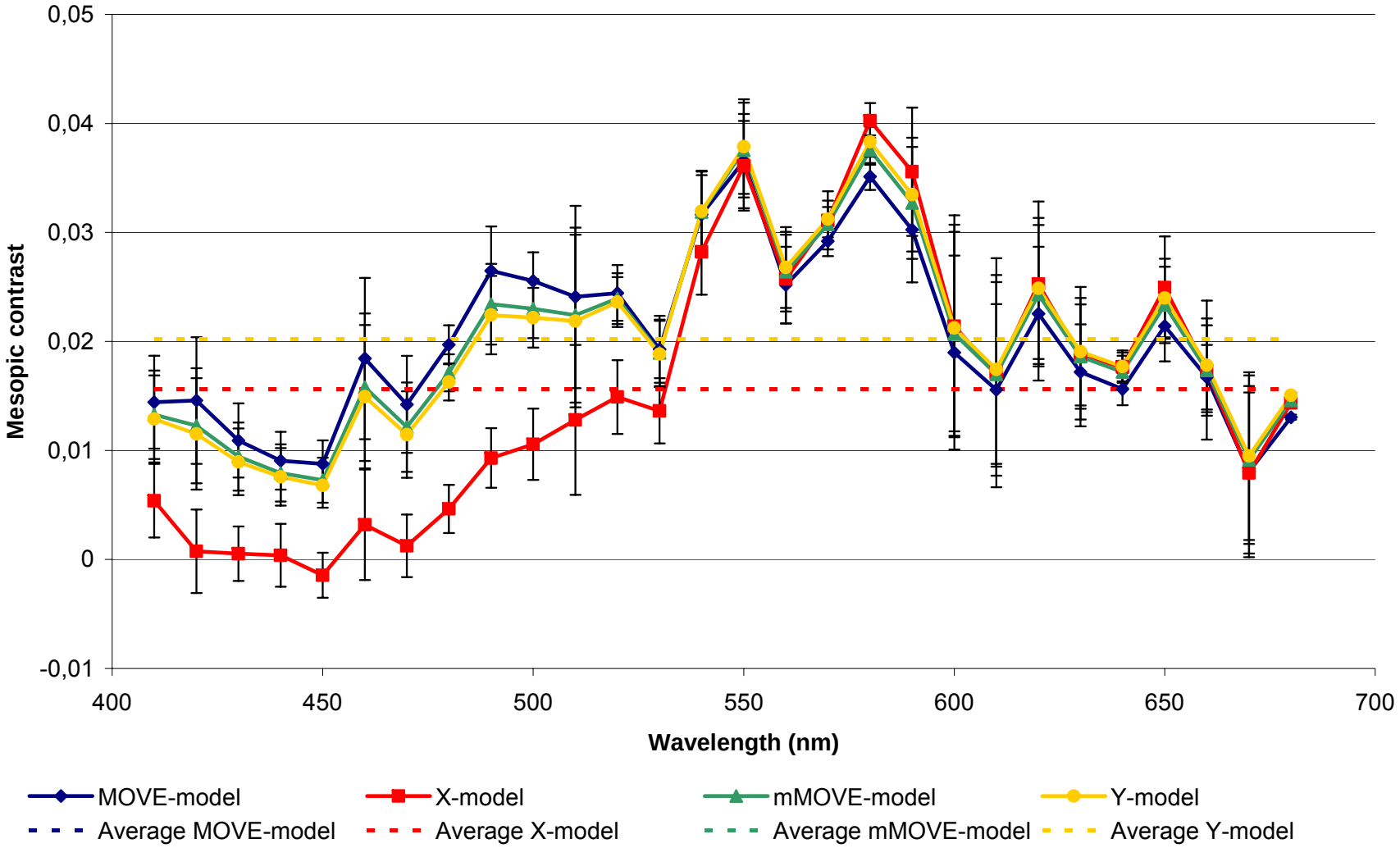


# L-LAB Detection Threshold Data

**a**

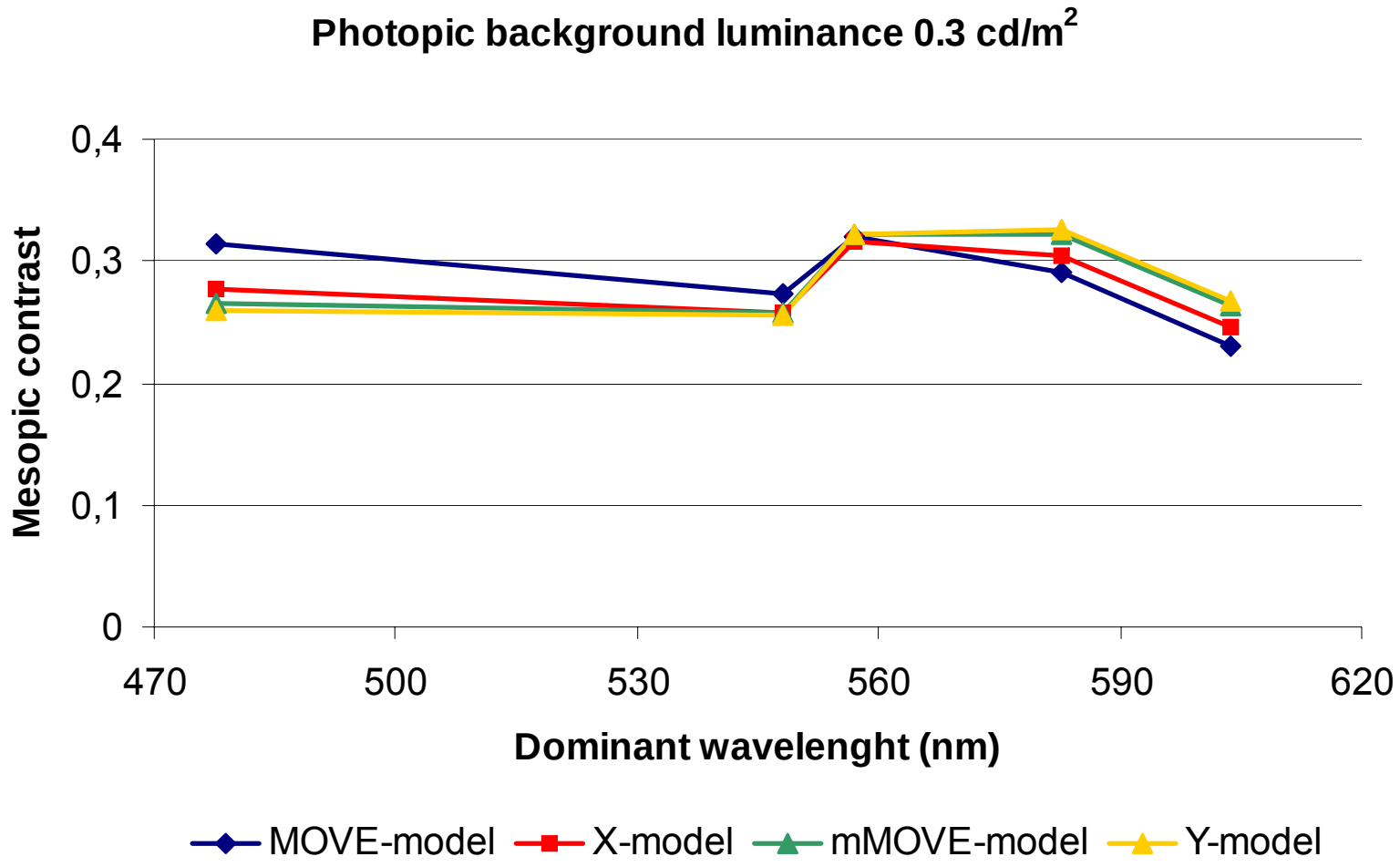


# UP Detection Threshold Data



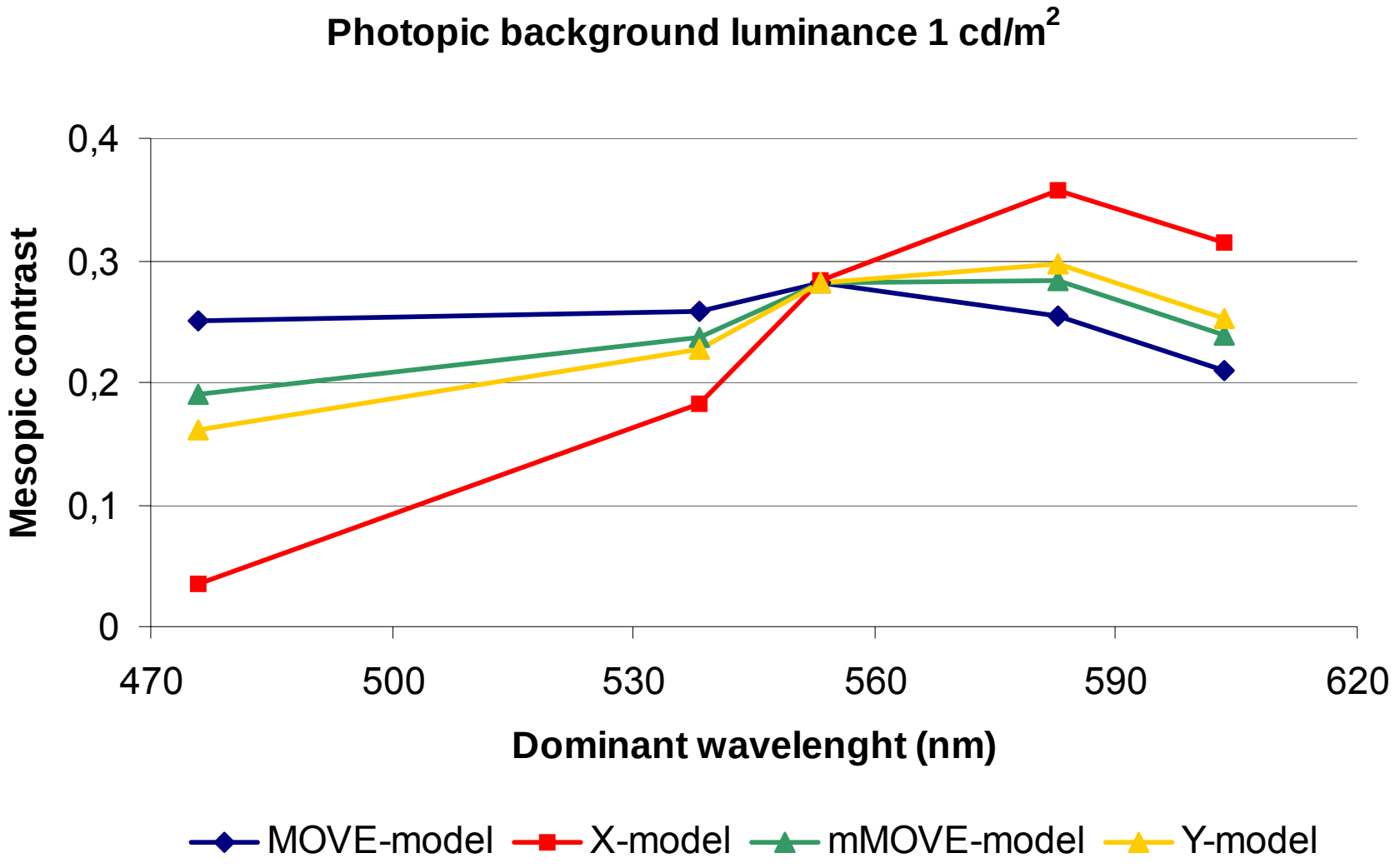
# TKK RT Data

**b**


Photopic background luminance 0.3 cd/m2
Mesopic contrast
0,4
0,3
0,2
0,1
0
470
500
530
560
590
620
Dominant wavelenght (nm)
MOVE-model
X-model
mMOVE-model
Y-model

# TKK RT Data

c


Photopic background luminance 1 cd/m2
Mesopic contrast
0,4
0,3
0,2
0,1
0
470
500
530
560
590
620
Dominant wavelenght (nm)
MOVE-model
X-model
mMOVE-model
Y-model

# Summary of Test Results

| | L [cd/m2] | | MOVE | X | modified MOVE | Y |
|---|---|---|---|---|---|---|
| L-LAB Detection threshold | 0.01 | 2° | 0,1738 | 0,2076 | **0,1557** | 0,1743 |
| | | 6° | 0,0482 | 0,0758 | **0,0317** | 0,0469 |
| | | 10° | 0,0159 | 0,0553 | **0,0108** | 0,0183 |
| | | 14° | **0,0115** | 0,0877 | 0,0299 | 0,0134 |
| | 0.07 | 2° | 0,0509 | 0,0669 | **0,0445** | 0,0469 |
| | | 6° | 0,0238 | 0,0361 | **0,0186** | 0,0204 |
| | | 10° | 0,0148 | 0,0282 | **0,0110** | 0,0121 |
| | | 14° | **0,0110** | 0,0338 | 0,0124 | 0,0106 |
| | 0.7 | 2° | 0,0117 | 0,0105 | 0,0090 | **0,0081** |
| | | 6° | 0,0114 | 0,0154 | **0,0090** | 0,0092 |
| | | 10° | **0,0101** | 0,0217 | 0,0112 | 0,0121 |
| | | 14° | **0,0140** | 0,0330 | 0,0156 | 0,0171 |
| | 8 | 2° | **0,0066** | 0,0075 | 0,0075 | 0,0075 |
| | | 6° | **0,0076** | 0,0087 | 0,0087 | 0,0087 |
| | | 10° | **0,0104** | 0,0119 | 0,0119 | 0,0119 |
| | | 14° | **0,0162** | 0,0187 | 0,0187 | 0,0187 |
| UP Detection threshold | 0.5 | 20° | **0,0078** | 0,0120 | 0,0085 | 0,0087 |
| TKK Reaction time | 0.1 | 10° | 0,0910 | 0,2127 | 0,0885 | **0,0856** |
| | 0.3 | 10° | 0,0360 | **0,0301** | 0,0335 | 0,0352 |
| | 1 | 10° | **0,0261** | 0,1286 | 0,0386 | 0,0538 |
| | 3 | 10° | **0,0314** | 0,0861 | 0,0626 | 0,0861 |
| | 10 | 10° | **0,0580** | 0,0657 | 0,0657 | 0,0657 |

# Summary

- General comparison for HPS and daylight MH:
  - differences between the X-, MOVE-, Y- and modified MOVE-models
  - differences in predicted mesopic luminances more pronounced at low light levels and with higher S/P-ratio
- X-, MOVE-, Y- and modified MOVE-models were compared with three independent visual performance data-sets (CT, RT). Best descriptions of data-sets (altogether 22)

| | |
|---|---|
| MOVE: | 12 |
| Modified MOVE: | 7 |
| Y: | 2 |
| X: | 1 |

- All models fail to describe near foveal data at low luminance levels

# Summary

- X-model produced largets standard deviations throughout L-Lab detection threshold data
- L-Lab detection threshold data best described by modified MOVE-model at lowest luminances untill $10^0$ eccentricity and MOVE-model at $14^0$ eccentricity
- MOVE-model described UP detection threshold data better than the other models
- TKK reaction time data: Y-model performed best at 0.1 cd/m$^2$, X-model performed best at 0.3 cd/m$^2$ and MOVE-model performed best at 1, 3 and 10 cd/m$^2$
- MOVE-model best at the highest luminance levels, although differences were small between V($\lambda$) and MOVE at 8 and 10 cd/m$^2$

# Mesopic Threshold Experiments -UP

- Mesopic detection threshold experiment with quasi-monochromatic red (620nm) and green (540nm) light increment stimuli on an achromatic background, also additive mixture of red and green ("two-peak" yellow)
- Achromatic background at 0.5 cd/m$^2$.
  2° disk presented 20° off-axis as a light increment on the background
- Probit analysis: 50% threshold radiance of the light increment and its 95% confidence limits
- Define values of NA (non-additivity) for modelling spectral non-additivity
- The value of NA (%) may serve as an estimate for the accuracy of the photometric model for composite i.e. non-quasi-monochromatic target SPDs.
- The new NA-formula should include chromatic terms to account for spectral non-additivity in those tasks where this NA-correction seems necessary
- Experiments are underway (1 subject tested out of 6)

# Criteria: Trend (?) Analysis

- Presentation of visual performance as a function of luminance

- To judge the suitablity of the model predictions, the visual performance data should decrease monotonically with background (mesopic) luminance

- The shape of this monotonically decreasing function probably follows a power function with a negative exponent (i.e. higher visual performance associated with highest luminance)

# Driver Decision Data -LRC

## Realistic driving experiment


- driving along public roadway illuminated by

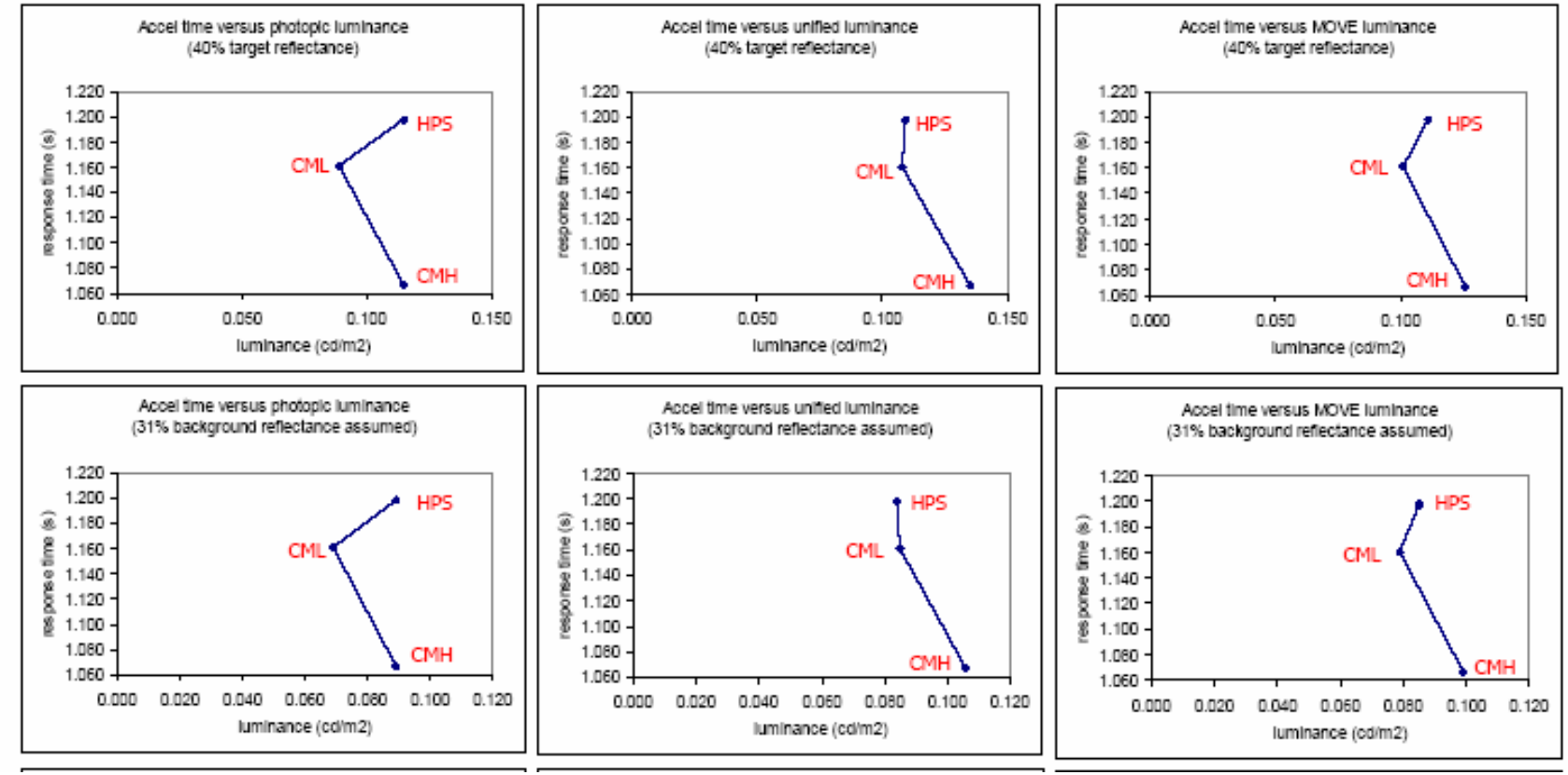
  HPS (S/P=0.55) – target $L_p$=0.057 cd/m$^2$
  CMH (S/P=1.17) – target $L_p$=0.057 cd/m$^2$
  CML (S/P=1.17) – target $L_p$=0.030 cd/m$^2$
  + car headlights

- peripheral detection targets moving toward/away from roadway
- subjects asked to
  - deccelerate (brake) if target moving toward the road
  - accelerate if target moving away from the road
- use of hypothethical background reflectances of 31%, 22%, 13%, 4% (equally spaced reflectances between 40% and 4%) to calculate background luminances
- presentation of response time in terms of target and background luminances calculated with V($\lambda$), X- and MOVE-models

# Driver Decision Data -LRC

Acceleration times as a function of target luminance (top row) and luminances for different assumed background reflectances (31%, 22%, 13%, 4%; lower rows).

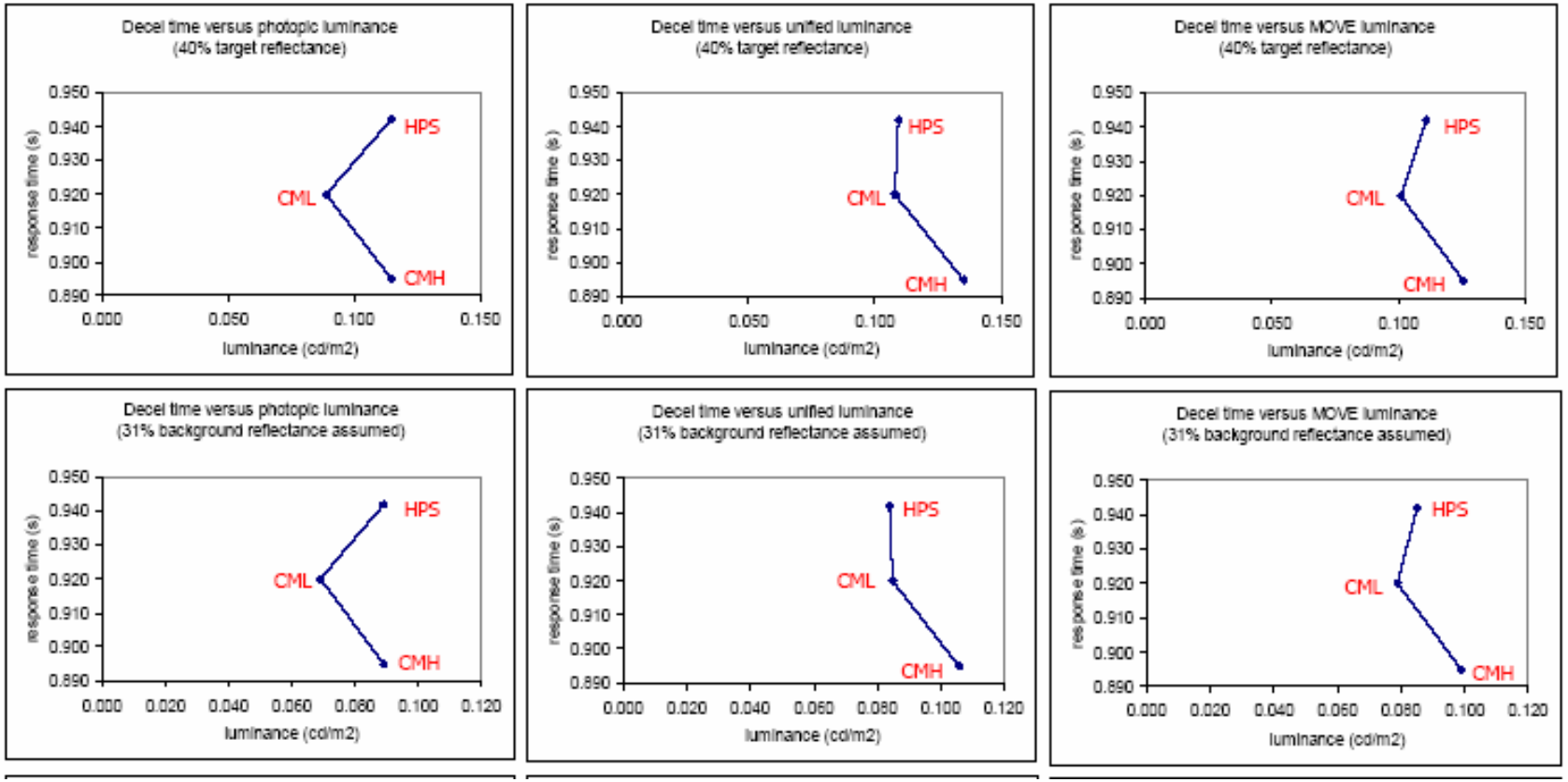
**V(λ)** **X** **MOVE**



# Driver Decision Data -LRC

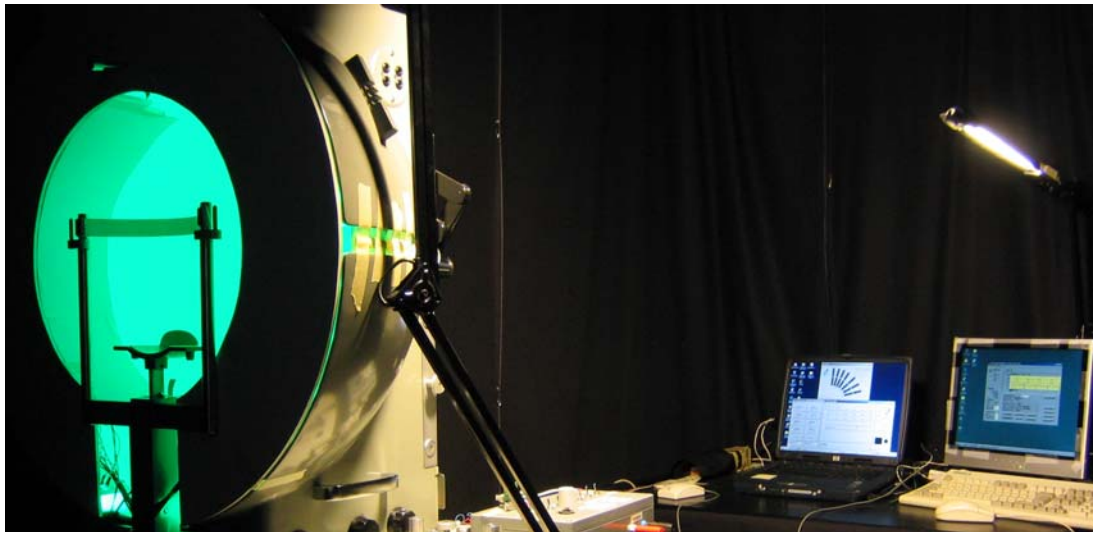
Deceleration times as a function of target luminance (top row) and luminances for different assumed background reflectances (31%, 22%, 13%, 4%; lower rows).

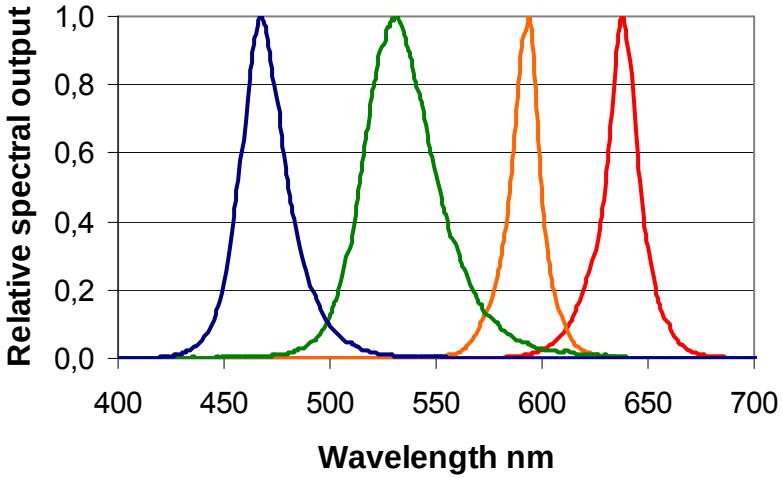
**V(λ)** **X** **MOVE**



# TKK RT and CT data

- CT
- RT at C = 0.05, 0.1, 0.15
- $L_b$ = 0.1 and 1 cd/m$^2$
- Four light spectra (achromatic contrast)
- 5 subjects

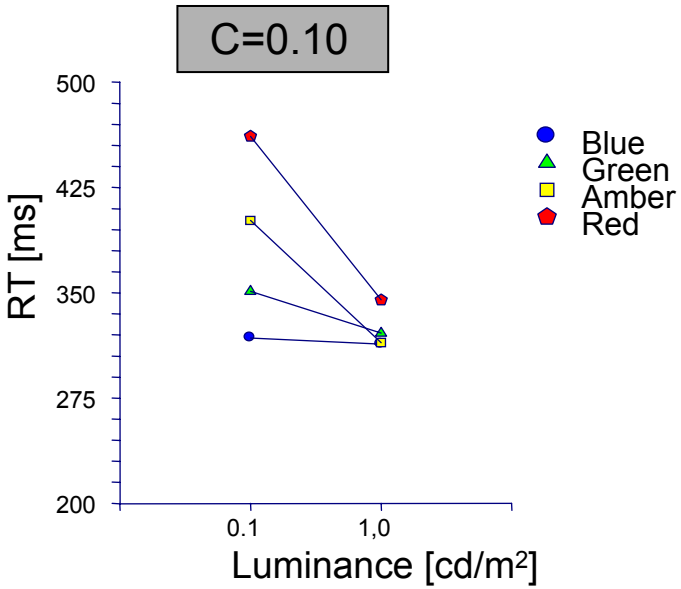


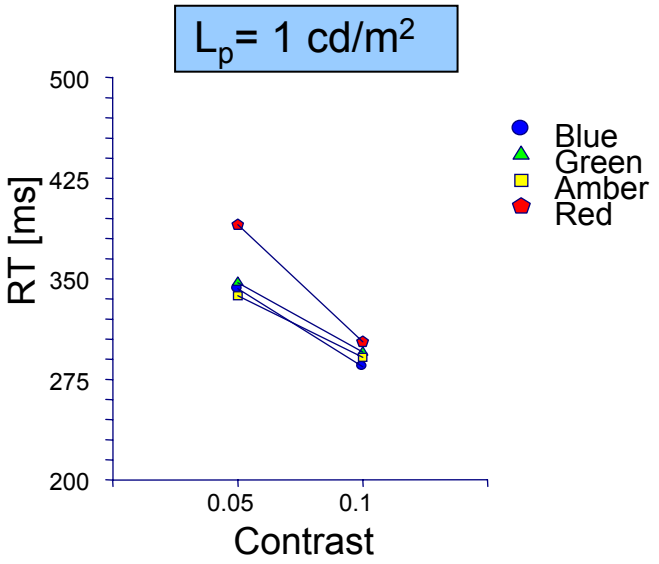


# Calculation of mesopic luminances

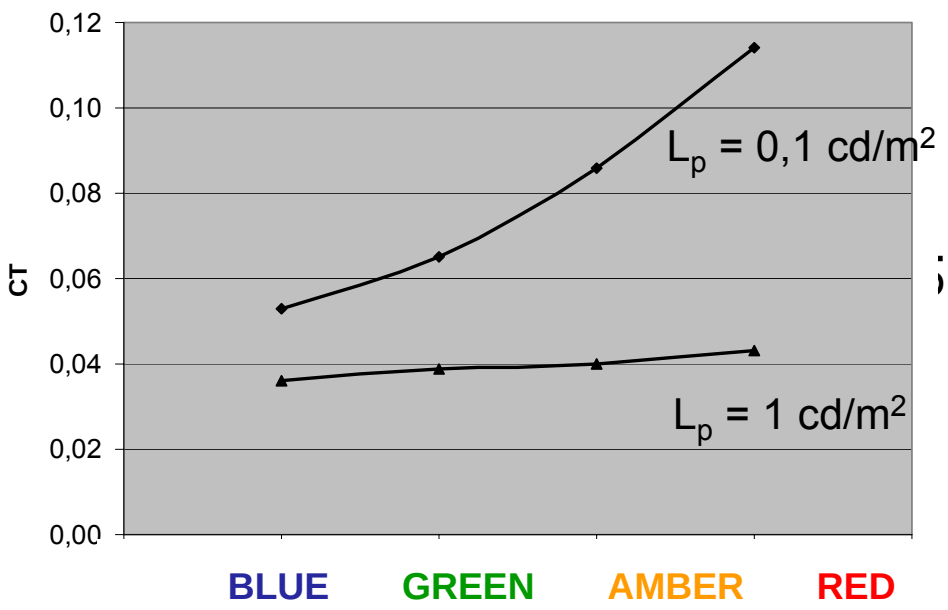
| Spectrum | S/P-ratio | $L_p$ = 1 cd/m$^2$ | | $L_p$ = 0.1 cd/m$^2$ | |
|---|---|---|---|---|---|
| | | $L_X$ | $L_{MOVE}$ | $L_X$ | $L_{MOVE}$ |
| Blue | 13.9 | 1 | 2.259 | 0.367 | 0.405 |
| Green | 2.09 | 1 | 1.159 | 0.159 | 0.139 |
| Amber | 0.239 | 1 | 0.872 | 0.034 | 0.064 |
| Red | 0.0396 | 1 | 0.835 | 0.007 | 0.050 |

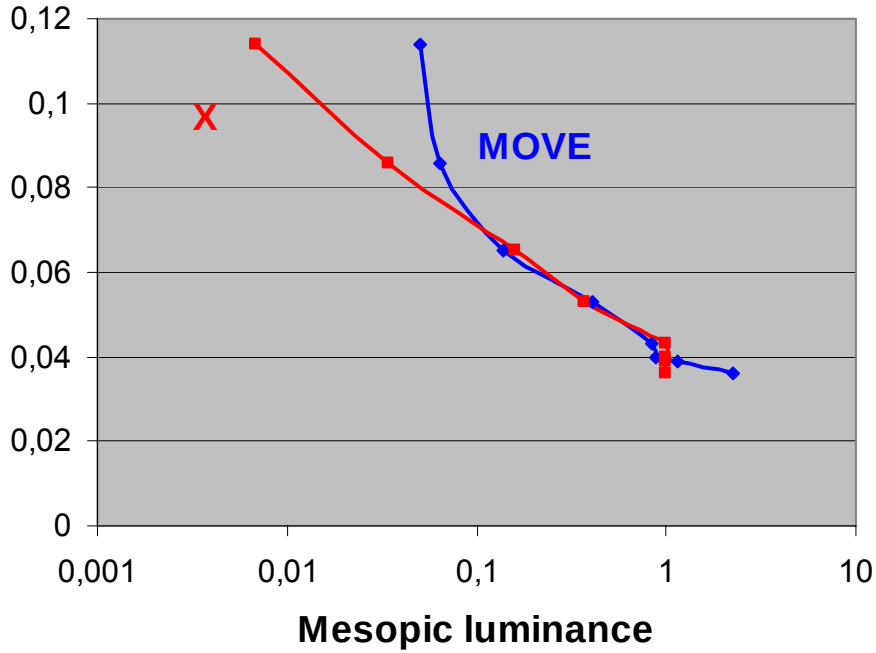
# RT data


C=0.10
500
425
350
275
200
RT [ms]
0.1
1,0
Luminance [cd/m2]
Blue
Green
Amber
Red

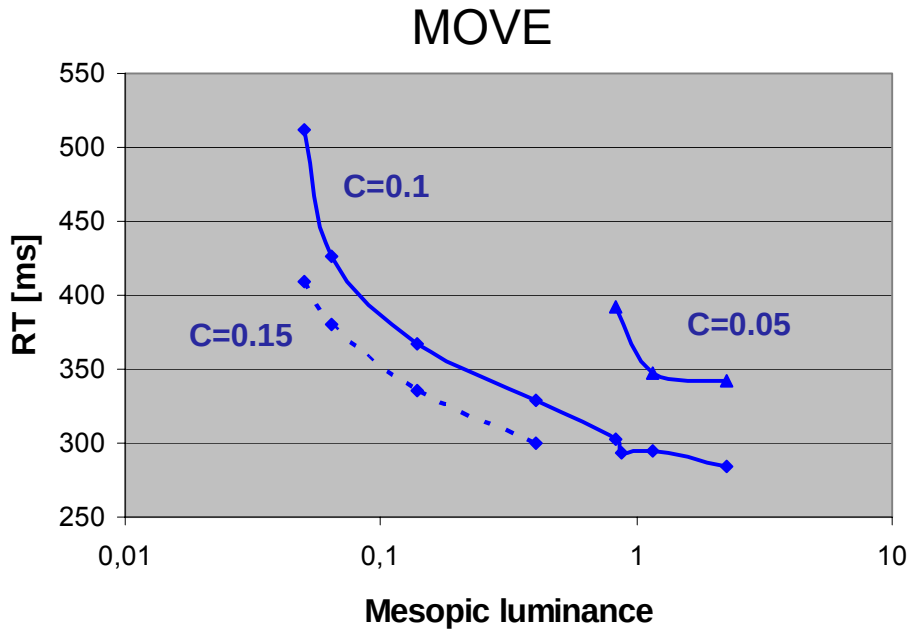

Lp= 1 cd/m2
500
425
350
275
200
RT [ms]
0.05
0.1
Contrast
Blue
Green
Amber
Red

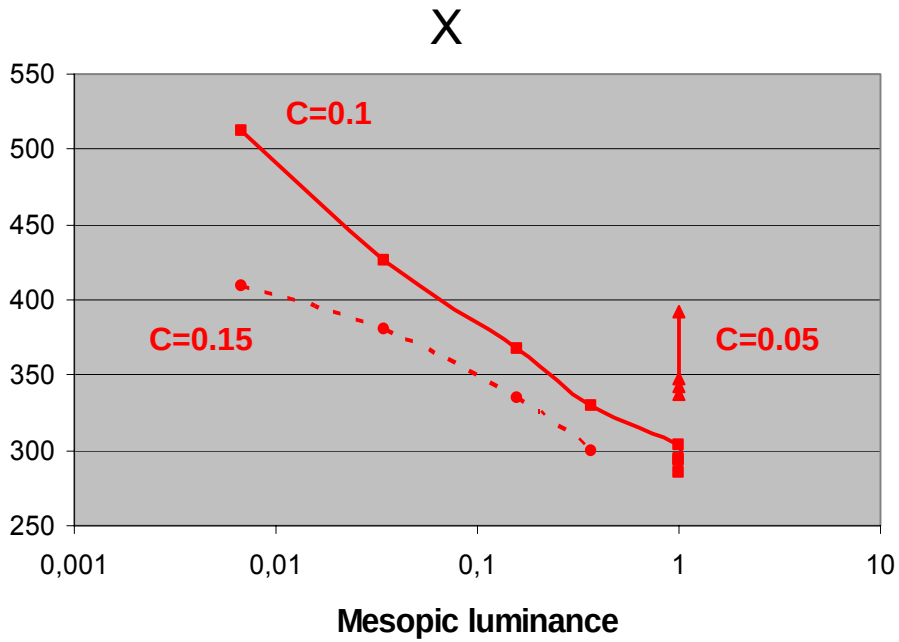
# TKK CT Data


0,12
0,10
0,08
0,06
0,04
0,02
0,00
CT
$L_p$ = 0,1 cd/m$^2$
$L_p$ = 1 cd/m$^2$
BLUE
GREEN
AMBER
RED


0,12
0,1
0,08
0,06
0,04
0,02
0
X
MOVE
0,001
0,01
0,1
1
10
Mesopic luminance

# TKK RT data




- RT decreasing with increasing luminance for all three contrasts
- shape of the RT curve similar for all contrasts

- RT decreasing with increasing luminance for two contrasts
- for the lowest contrast RT varies between different spectra, although the predicted background luminance is the same
- shape of the RT curve different for all contrasts