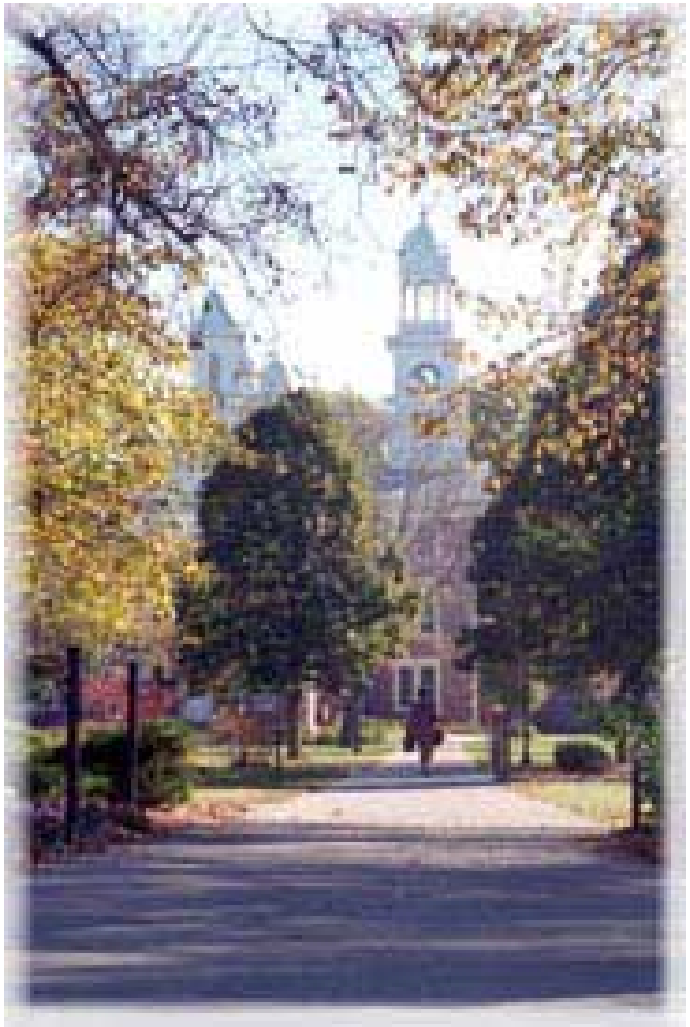

# Visual Entropy and Drivers' Eye Gaze Complexity as a Function of Age and SubsidiaryTask Load

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**HFES – September 2008**
**New York, NY**

Given that driving is highly dependent upon visual-spatial processing…It's logical to assume that eye movement behavior might change systematically with increases in driver mental workload.

Indeed, Recarte & Nunes (2000) demonstrated that the distribution of driver eye glances became spatially restricted when visual-spatial demands were experimentally increased.

# Literature Search for Global Measures of EM Complexity yielded 2 Candidates

**Spectral Analysis**

- Based upon Fourier Theorem
- Global measure of temporal complexity
- Discards spatial component of behavior

**Entropy**

- Based upon Information Theory
- Global measure of spatial complexity (1/redundancy)
- Discards temporal variations in behavior

At least two previous studies have reported findings suggesting that **ENTROPY** measures of eye movement data covary with visual task load:

Tole, Stephens, Vivaudou, Ephrath & Young (1983).
*Visual scanning behavior and pilot workload*. NASA Contractor Report 3717. Cambridge, MA: Massachusetts Institute of Technology.

Ellis (1986). Statistical dependency in visual scanning.
*Human Factors*, 28(4), 421-438.

# Operational Definition: **Complexity**

[within the context of Information Theory]

The amount of information required
to specify the behavior of a system.

The more information required….
The greater the complexity of the system.

Information theory (Shannon, 1946) provides a theoretical and computational basis for quantifying the amount of information required to characterize a system.

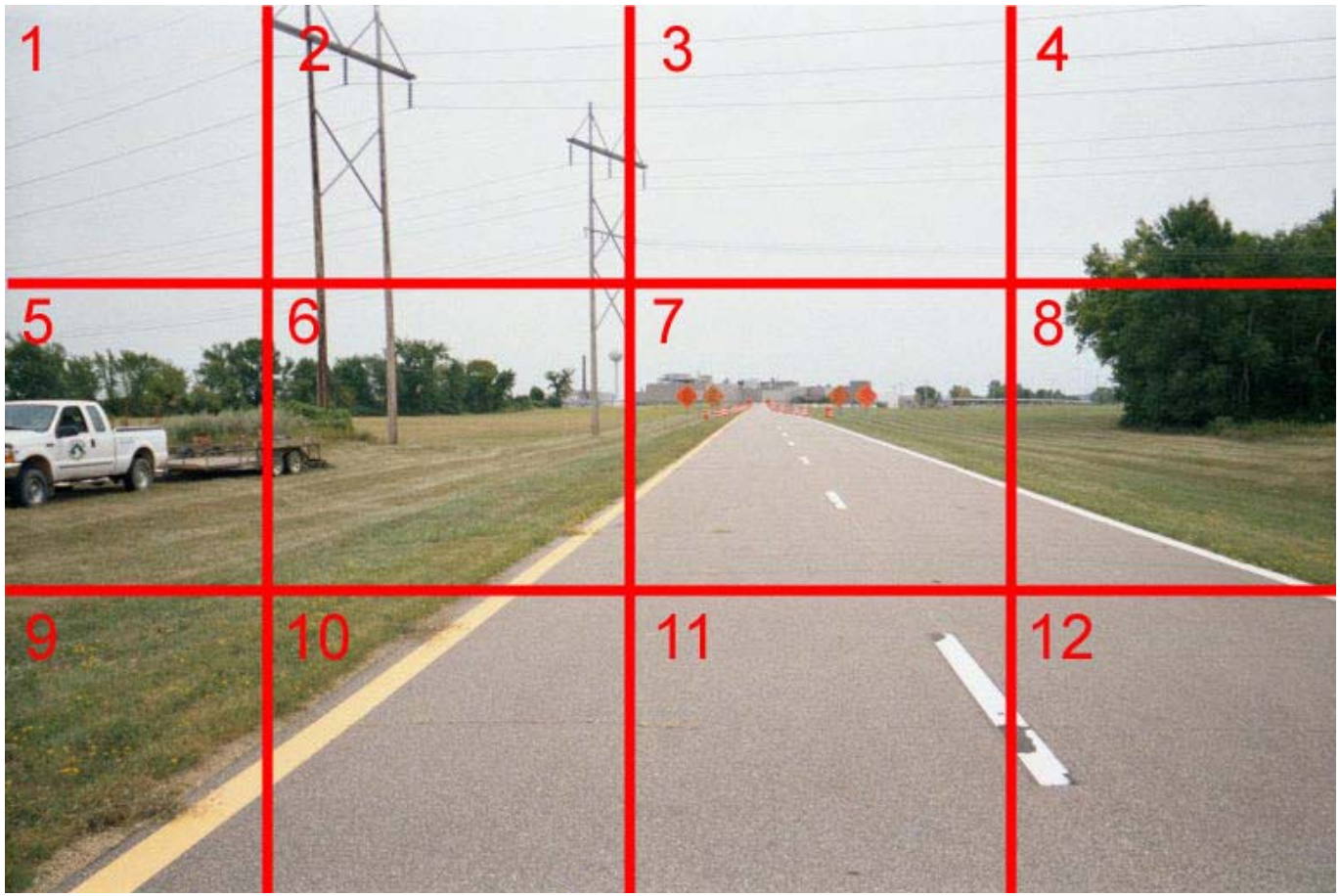
This metric has become known as “Shannon entropy”, or more simply, as **entropy**.

Computation of an entropy metric
requires one to define:

(1) a **state-space** representing the system; and
(2) the respective **probabilities** for each
element in that state-space.

Development of a state-space to represent driver eye gaze behavior can be done either arbitrarily or theoretically.

# Example of an arbitrary state-space



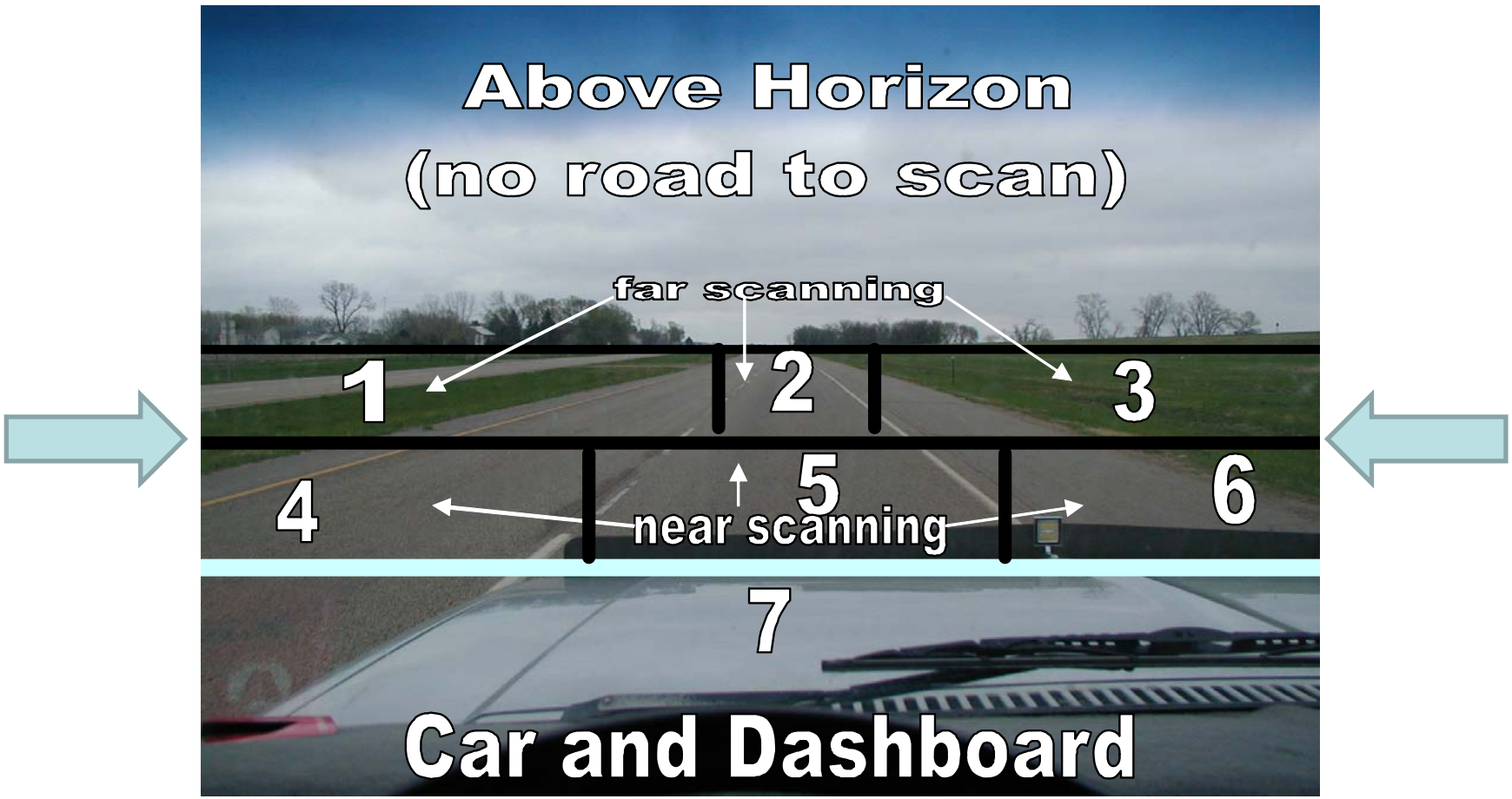
We chose to define the driver's eye gaze state-space on the basis of two theoretically derived heuristics:

Donges' (1978) **near vs. far** dual visual process model of vehicular guidance

Leibowitz & Owens' (1977) **focal-ambient** dichotomy of driver visual processing

# Driver Eye Gaze Behavior (Static) State-Space

(near distance criterion < 1.8 sec preview time)
(focal area criterion = within driver's lane)



# 1st-order Markov Chain Entropy Metric

Computes entropy (1/redundancy) based upon the conditional probabilities of eye gaze transitions from $state_i$ to $state_j$

$$\mathbf{H(Y|X) = -\sum_{i=1}^{n}\sum_{j=1}^{m} p(Y_{ij}\,|X_i)\,\log_2\,p(Y_{ij}\,|X_i)\,p(X_i)}$$

(see van der Lubbe, 1997)

| Prior State ($X_i$) | Present State $p(Y_{ij}\|X_i)$ 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | ------ | 0.166 | 0.166 | 0.166 | 0.166 | 0.166 | 0.166 |
| 2 | 0.166 | ------ | 0.166 | 0.166 | 0.166 | 0.166 | 0.166 |
| 3 | 0.166 | 0.166 | ------ | 0.166 | 0.166 | 0.166 | 0.166 |
| 4 | 0.166 | 0.166 | 0.166 | ------ | 0.166 | 0.166 | 0.166 |
| 5 | 0.166 | 0.166 | 0.166 | 0.166 | ------ | 0.166 | 0.166 |
| 6 | 0.166 | 0.166 | 0.166 | 0.166 | 0.166 | ------ | 0.166 |
| 7 | 0.166 | 0.166 | 0.166 | 0.166 | 0.166 | 0.166 | ------ |

| a. $X_i$ | b. $-\sum_{j=1}^{m} p(Y_{ij}\|X_i) \log_2 p(Y_{ij}\|X_i)$ | c. $p(X_i)$ | d. product |
|---|---|---|---|
| 1 | 2.58 | 0.143 | 0.369 |
| 2 | 2.58 | 0.143 | 0.369 |
| 3 | 2.58 | 0.143 | 0.369 |
| 4 | 2.58 | 0.143 | 0.369 |
| 5 | 2.58 | 0.143 | 0.369 |
| 6 | 2.58 | 0.143 | 0.369 |
| 7 | 2.58 | 0.143 | 0.369 |

$$-\sum_{i=1}^{n}\sum_{j=1}^{m} p(Y_{ij}|X_i) \log_2 p(Y_{ij}|X_i)\, p(X_i) = 2.58 \text{ bits}$$

**Computational Example**:
(bits per glance transition)

Probability matrix representing RANDOM gaze transition behavior.

MAXIMUM ENTROPY occurs in the special case of random behavior (equiprobability).

Relative Entropy = entropy/Max

# Eye Movement Entropy Model (Markov Length = 2) has 42 states

| | | | | | | |
|---|---|---|---|---|---|---|
| ~~1,1~~ | 2,1 | 3,1 | 4,1 | 5,1 | 6,1 | 7,1 |
| 1,2 | ~~2,2~~ | 3,2 | 4,2 | 5,2 | 6,2 | 7,2 |
| 1,3 | 2,3 | ~~3,3~~ | 4,3 | 5,3 | 6,3 | 7,3 |
| 1,4 | 2,4 | 3,4 | ~~4,4~~ | 5,4 | 6,4 | 7,4 |
| 1,5 | 2,5 | 3,5 | 4,5 | ~~5,5~~ | 6,5 | 7,5 |
| 1,6 | 2,6 | 3,6 | 4,6 | 5,6 | ~~6,6~~ | 7,6 |
| 1,7 | 2,7 | 3,7 | 4,7 | 5,7 | 6,7 | ~~7,7~~ |

# (Markov Length = 3) Entropy Model has 252 unique transition states

1,2,1
~~1,2,2~~
1,2,3
1,2,4
1,2,5
1,2,6
1,2,7

= 6 New Sequences X 42 = 252

# The Experiment

- Eye movements recorded during 10 min drives on rural 2-lane highway (55 MPH)
- 3 driving conditions:
  - Baseline
  - Memory Load Task
  - Visual-spatial Load Task
- 2 Age Groups:
  - Young (n=10; mean age = 27)
  - Old (n=6; mean age = 75)

## **Memory Load Subsidiary Task**:

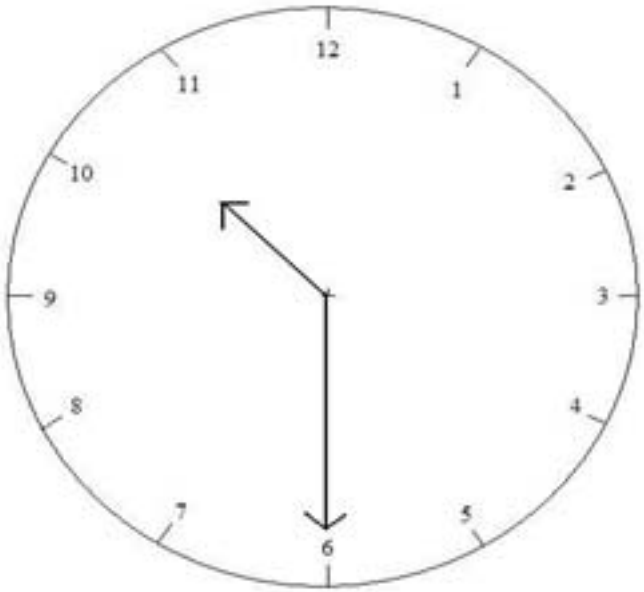
- 1-Back Task
- Quasi-random string of numerical digits
- Auditory presentation (subjective level adj.)
- Interstimulus interval = 4 sec
- Answer Yes/No question for each stimulus:
  Same as the previous stimulus?
- Responses recorded for off-line analysis

(2-Back control group not discussed in this report)

## Visual-Spatial Subsidiary Load Task: (The Clock Task)

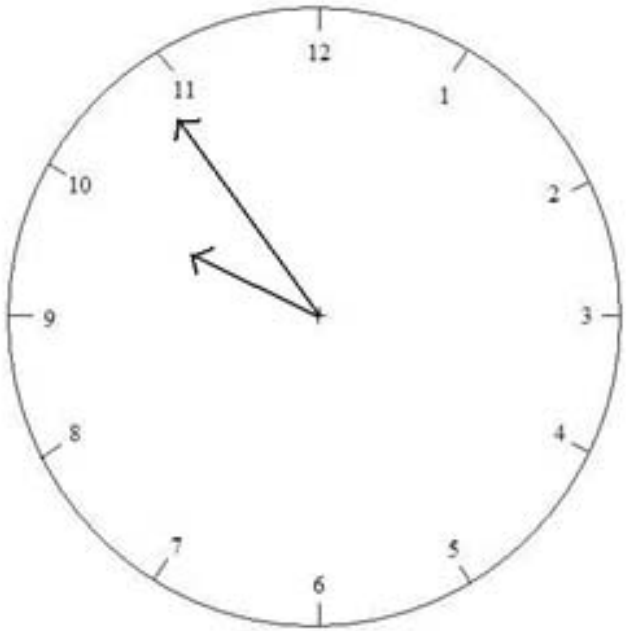
- Audio presentation of time-of-day stimulus (ISI = 8 sec)
- Form visual image of the time on the face of an imaginary analog clock
- Answer Yes/No Question:

  Is ANY angle formed by the hands of the clock < 90-deg?




"10:30"

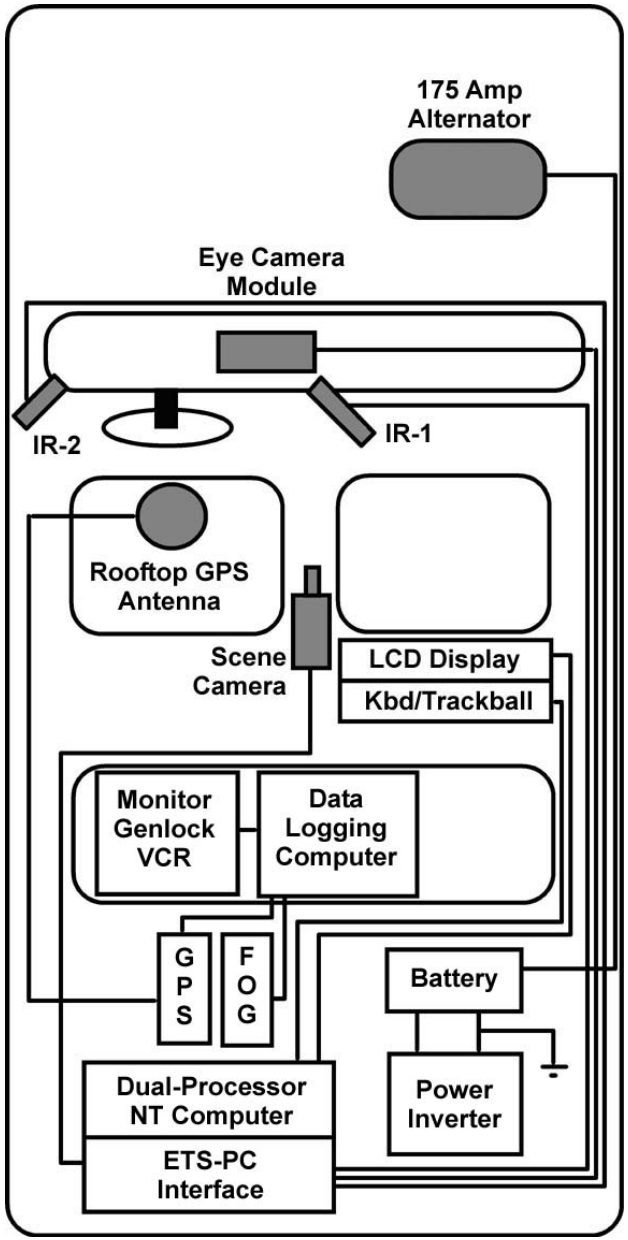
Correct answer = "No"




"9:54"

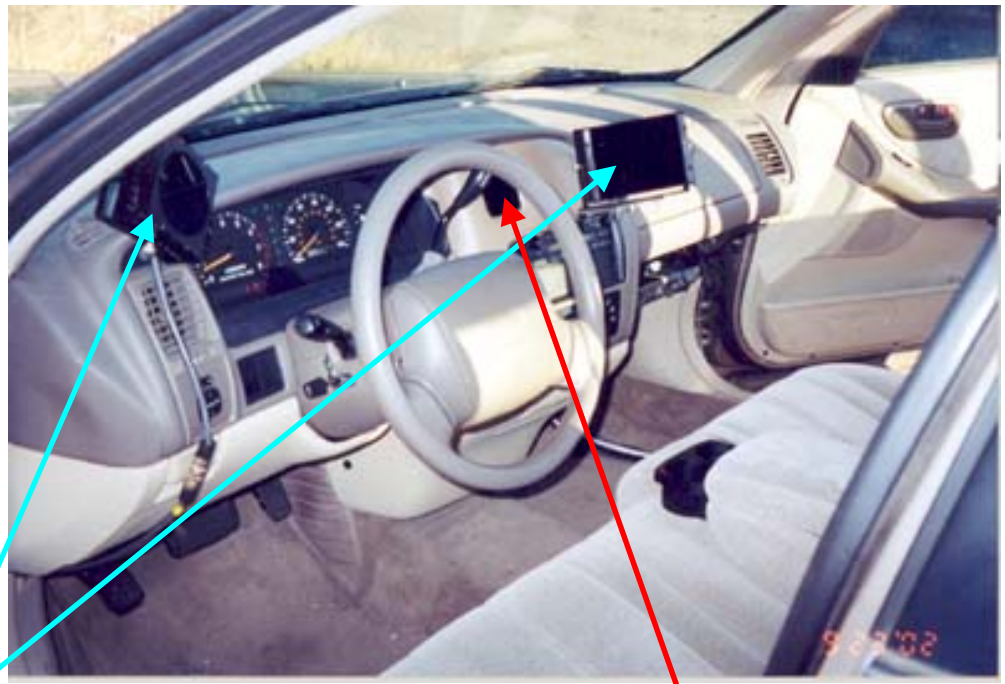
Correct answer = "Yes"

# USD Instrumented Research Vehicle




## ASL ETS-PC Eye Tracker

# ASL ETS-PC
# Driver Eye Tracking System



Infrared Illuminators
(source of corneal reflections)

Hidden Eye Tracker Optics

# Hypotheses

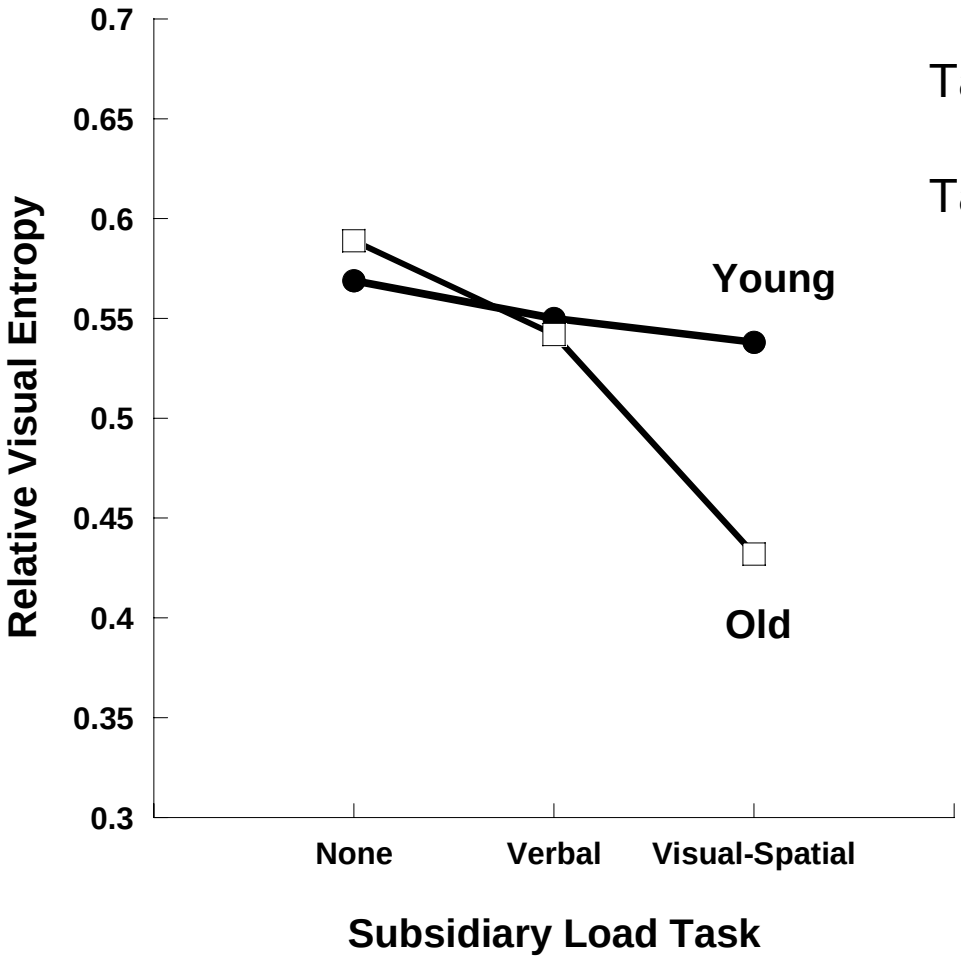
Eye gaze behavior will become less complex (more redundant) under the visual-spatial load condition…i.e., Visual entropy will decrease.

This effect will be exacerbated among the older drivers due to previously demonstrated declines in visual information processing efficiency/resources.

# Main Results

- Gaze data from each 10-min driving segment used to generate the conditional probability matrix needed to compute the visual entropy metric

- (2) Age by (3) Subsidiary Task Load ANOVA performed on the relative entropy data [Relative entropy = entropy / max. entropy]




Significant Age x Task Load Interaction

*Post hocs*:

Age @ Visual-Spatial

Task Load @ Young

Task Load @ Old

Visual-Spatial vs. Baseline (0.002)

Memory Task vs. Baseline (n.s.)

# Visual Entropy Results

# Some Closing Comments

- Need to explore improved sensitivity of entropy measure as a function of modifications in the state-space model

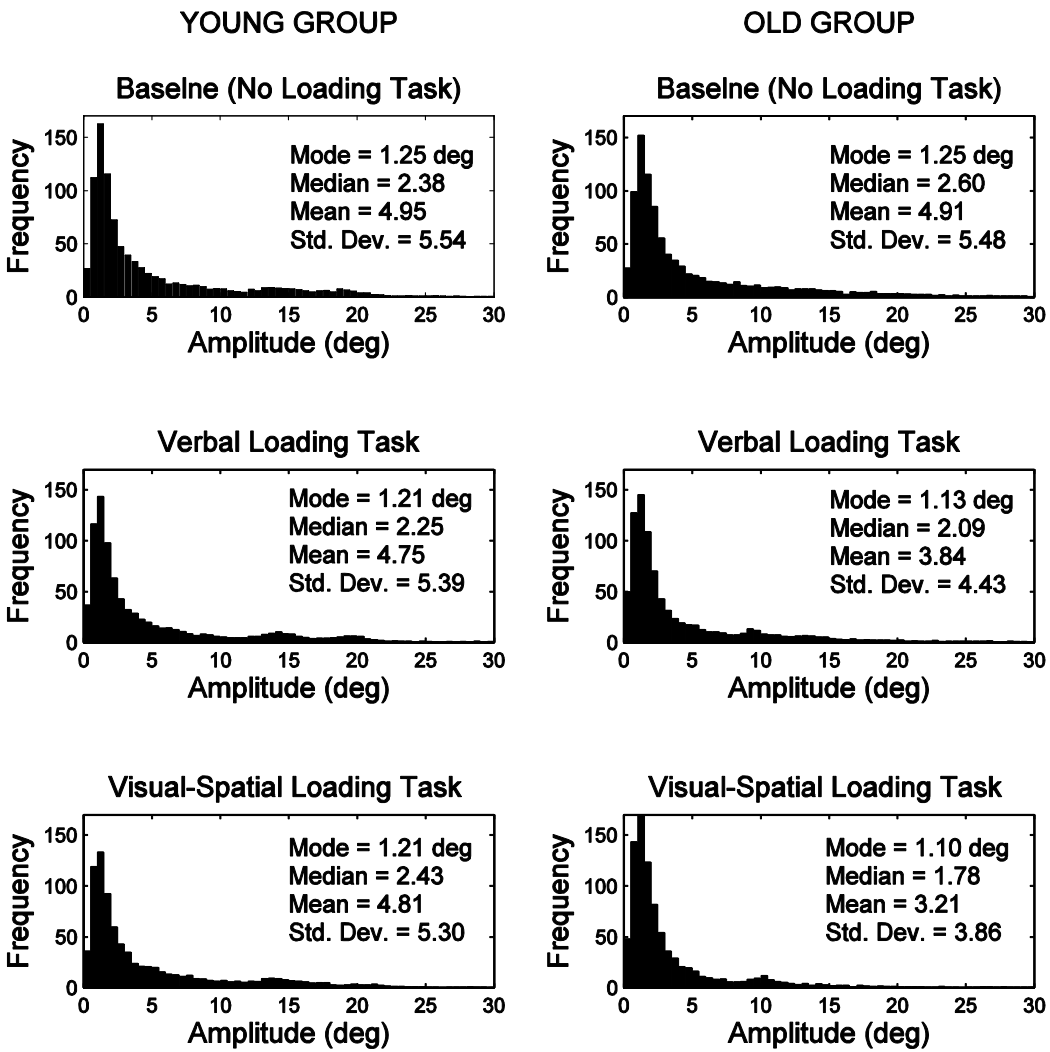
- Need to improve flexibility of our on-road eye tracking capabilities (Valid data could be collected from less than half of our older participants (bifocals; ptosis; etc.).

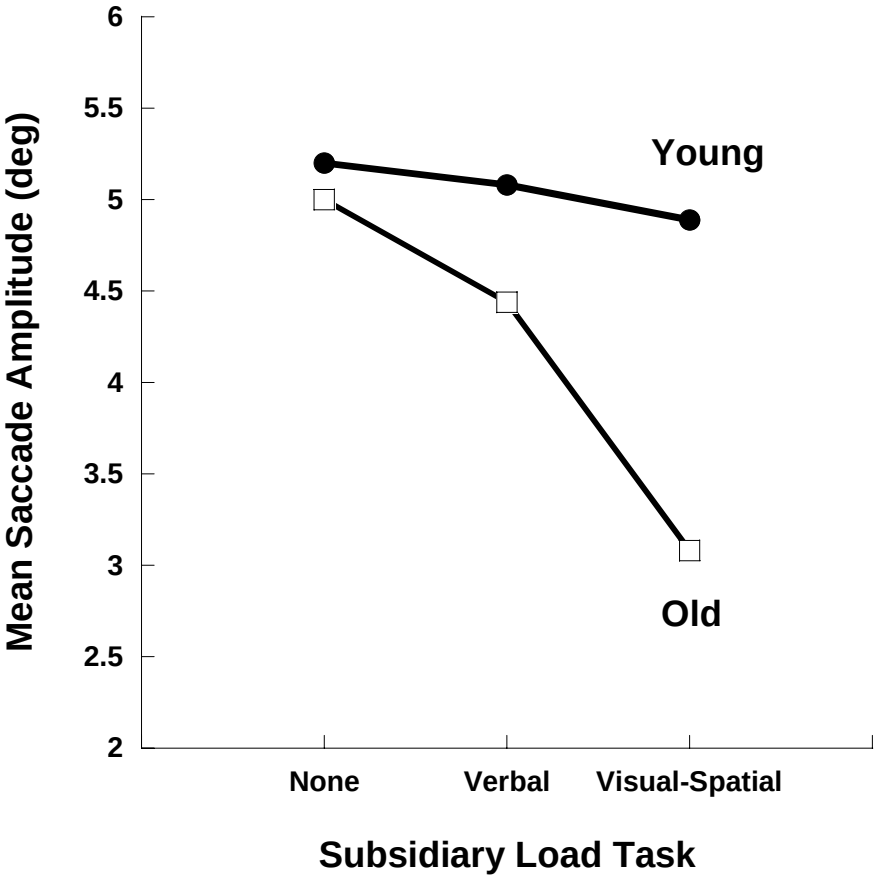
# Thanks for attending!

For additional information:
schieber@usd.edu

# APPENDIX

# Saccadic Amplitude Distributions






Significant Age by Task Interaction

*Post hocs:*

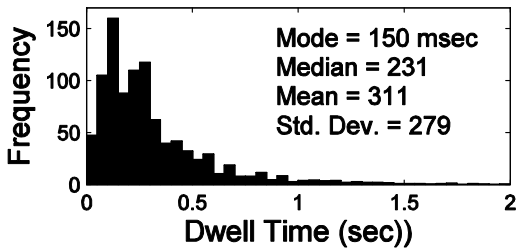
No age difference at any task level

Visual-spatial > Baseline (Old only)

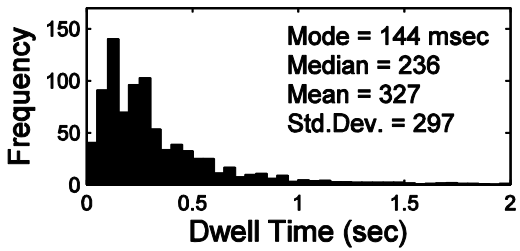
# Dwell Time Distributions

YOUNG GROUP

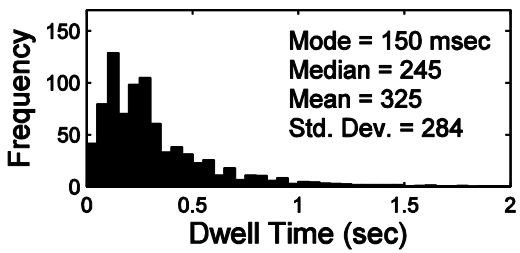
Baselne (No Loading Task)




Verbal Loading Task

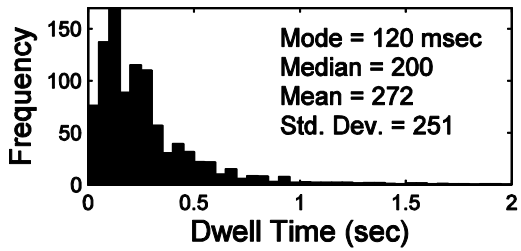



Visual-Spatial Loading Task

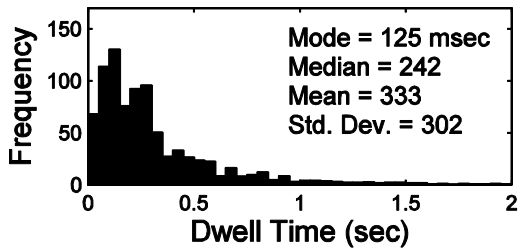



OLD GROUP

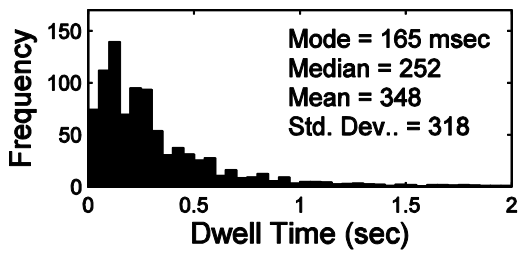
Baselne (No Loading Task)

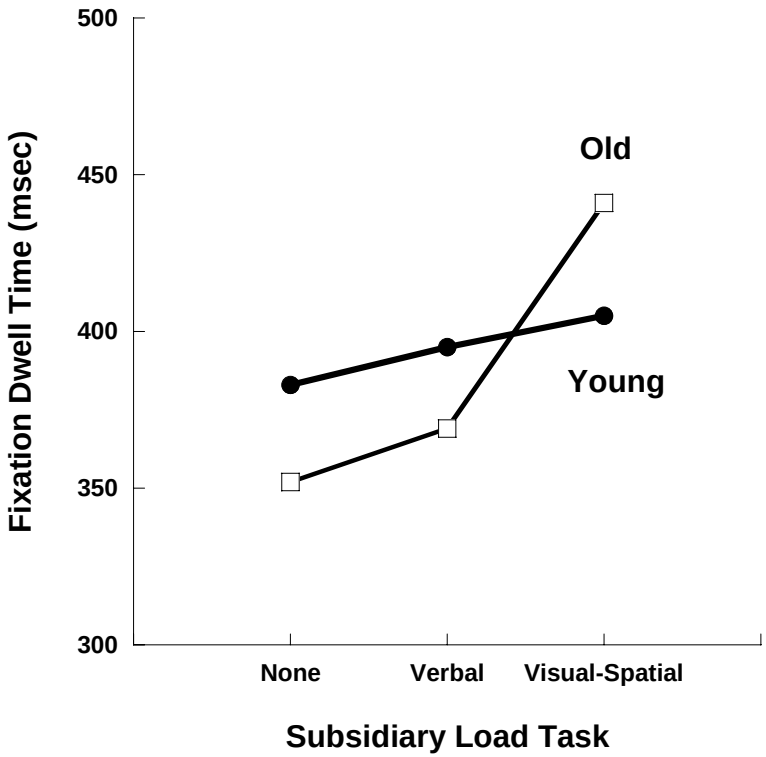



Verbal Loading Task




Visual-Spatial Loading Task

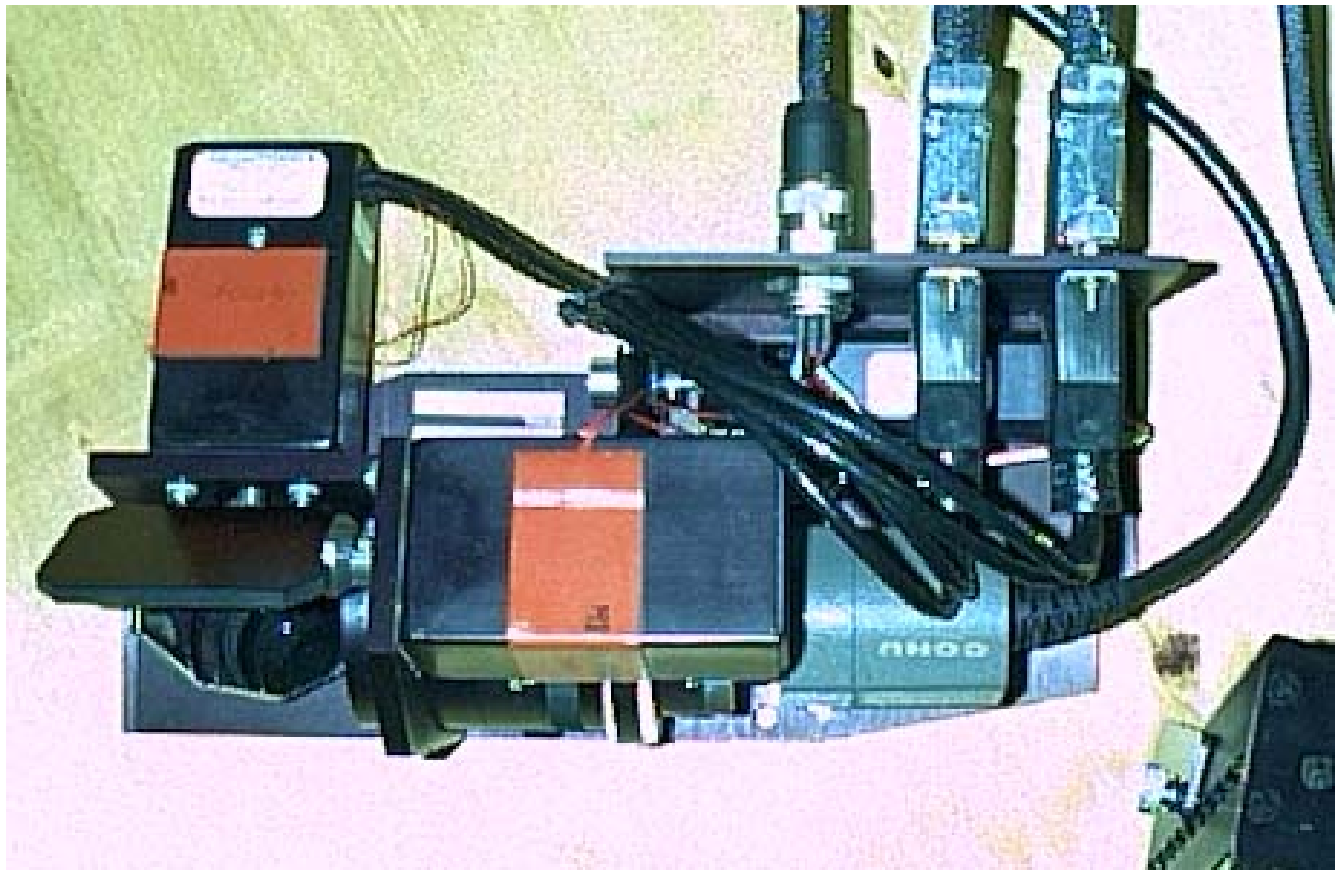




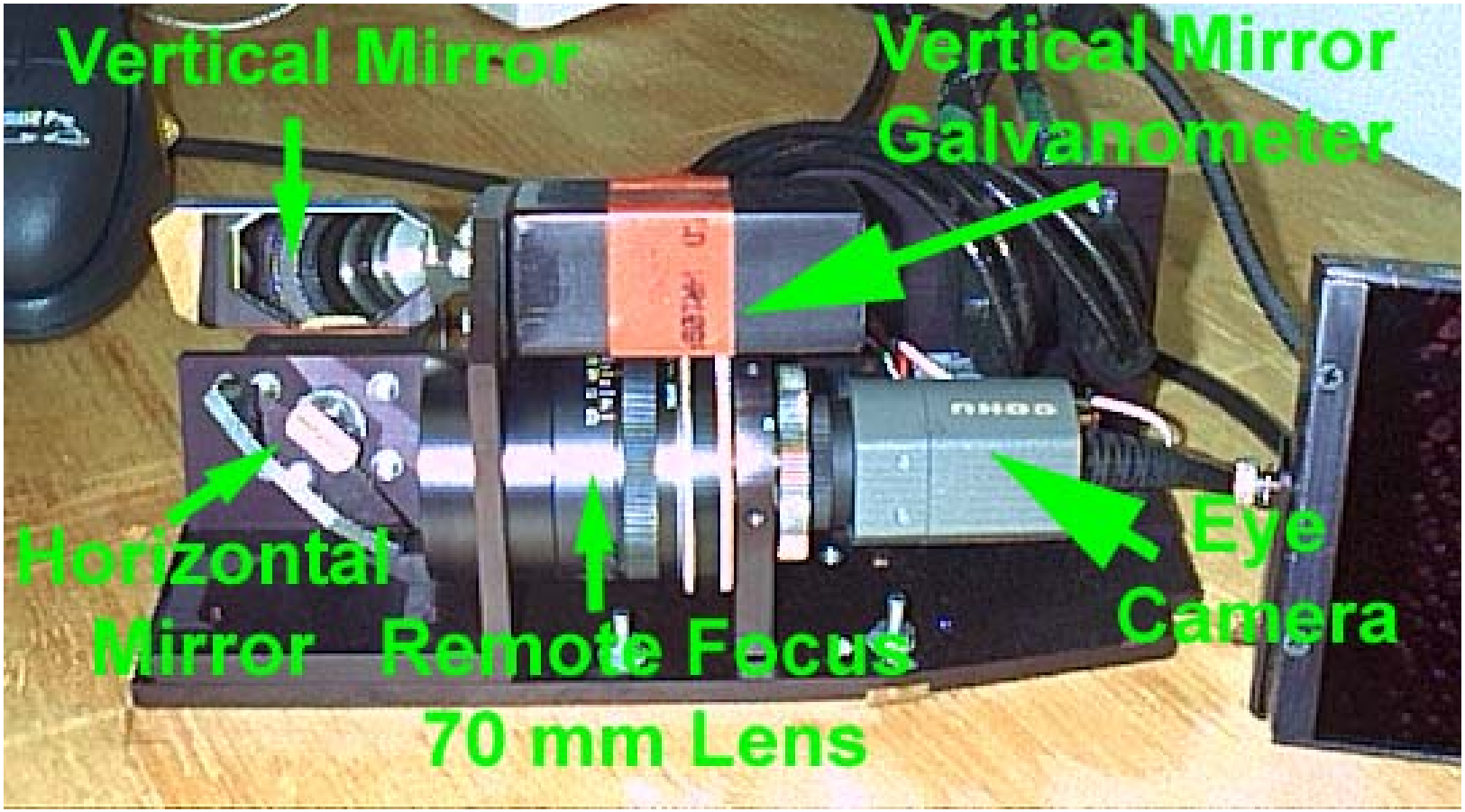

## Significant Age by Task Interaction

*Post hocs:*

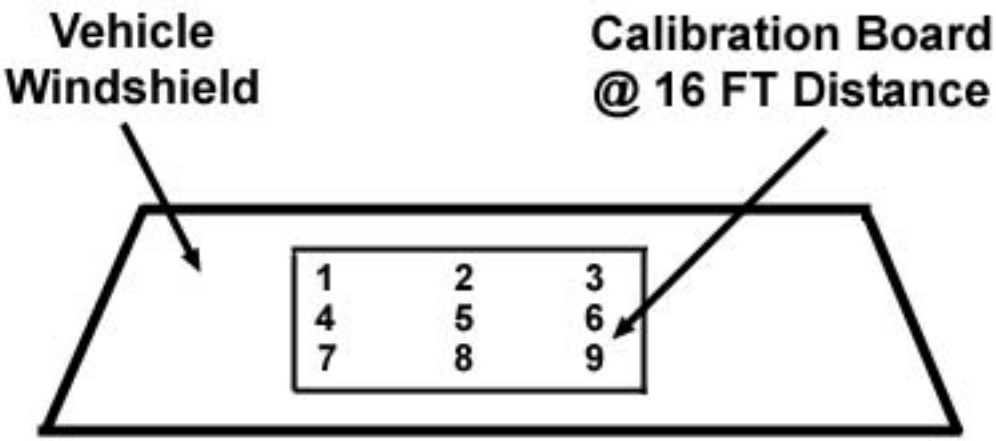
Visual-Spatial > Baseline (Old only)



Bird’s Eye View
ASL ETS-PC Optics Module

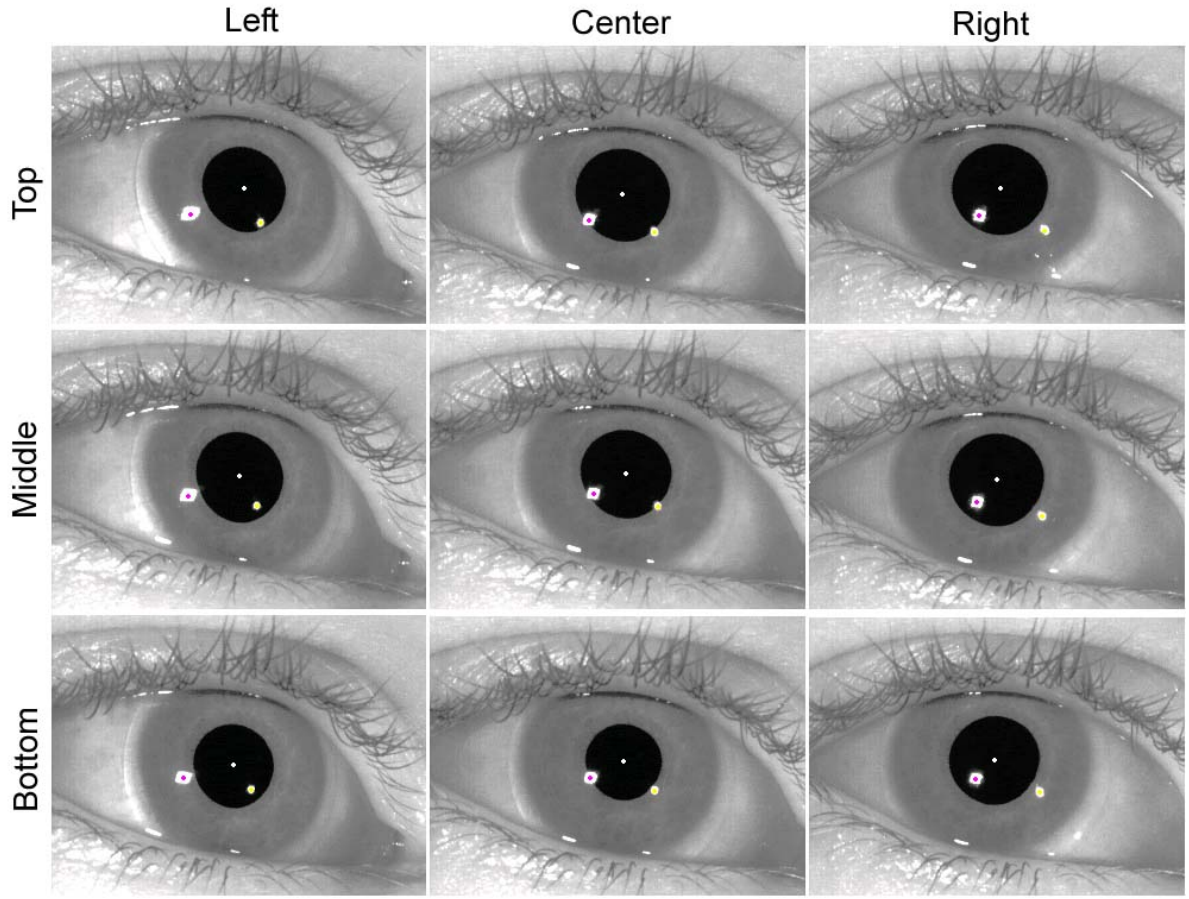



# ASL ETS-PC Optics Module




**Calibration Target #2.**
**Reading Distant Highway Signs**

# Calibration Scenario




# Position of Corneal Reflections Changes across Gaze Location