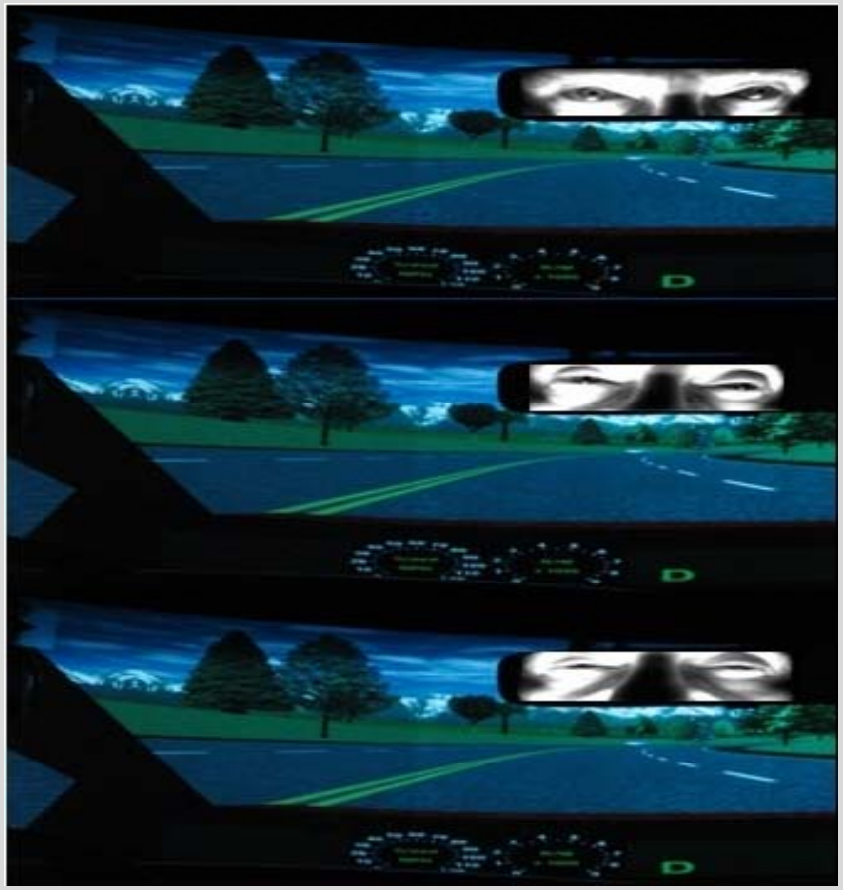
Oculometric Measures as an Index of Driver Distraction, Inattention, Drowsiness and Sleep Onset



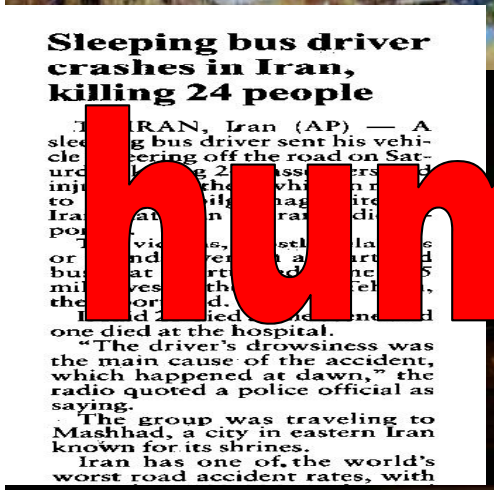
William Torch[1,2], MD, MS and Carlos Cardillo[2], MS

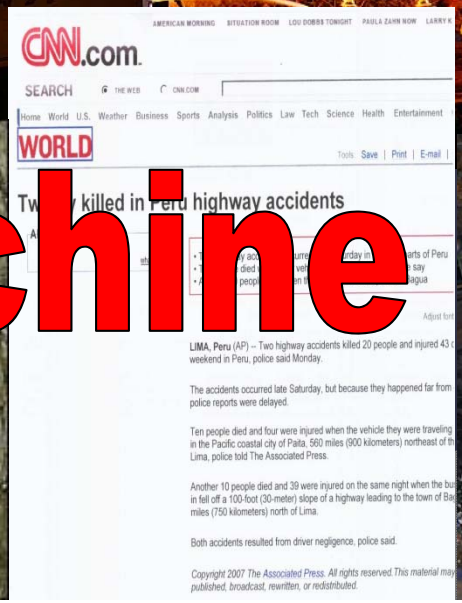
1 Washoe Sleep Disorders Center, Reno, NV USA

2 Eye-Com Corporation, Reno, NV USA

CAUSES OF DISTRACTION / INATTENTION RELATED ACCIDENTS

- **Sleep Disorders**
  - ✓ Obstructive Sleep Apnea
  - ✓ Narcolepsy
  - ✓ Insomnia
  - ✓ Restless Leg Syndrome and Periodic Limb Movements
  - ✓ Attention Deficit Disorder
- **Other Medical Conditions**
  - ✓ Chronic Medical Conditions
  - ✓ Chronically Painful Conditions
- **Life Style**
  - ✓ Shift Workers
  - ✓ Adolescent
  - ✓ Emotional Distress
  - ✓ Cell phones, Text Messaging, CD Players
- **Effect of Drugs & Substances that Disrupt Sleep**
  - ✓ Alcohol, Caffeine, Methamphetamines, etc.
  - ✓ Prescription Drugs or Over-the-Counter Drugs



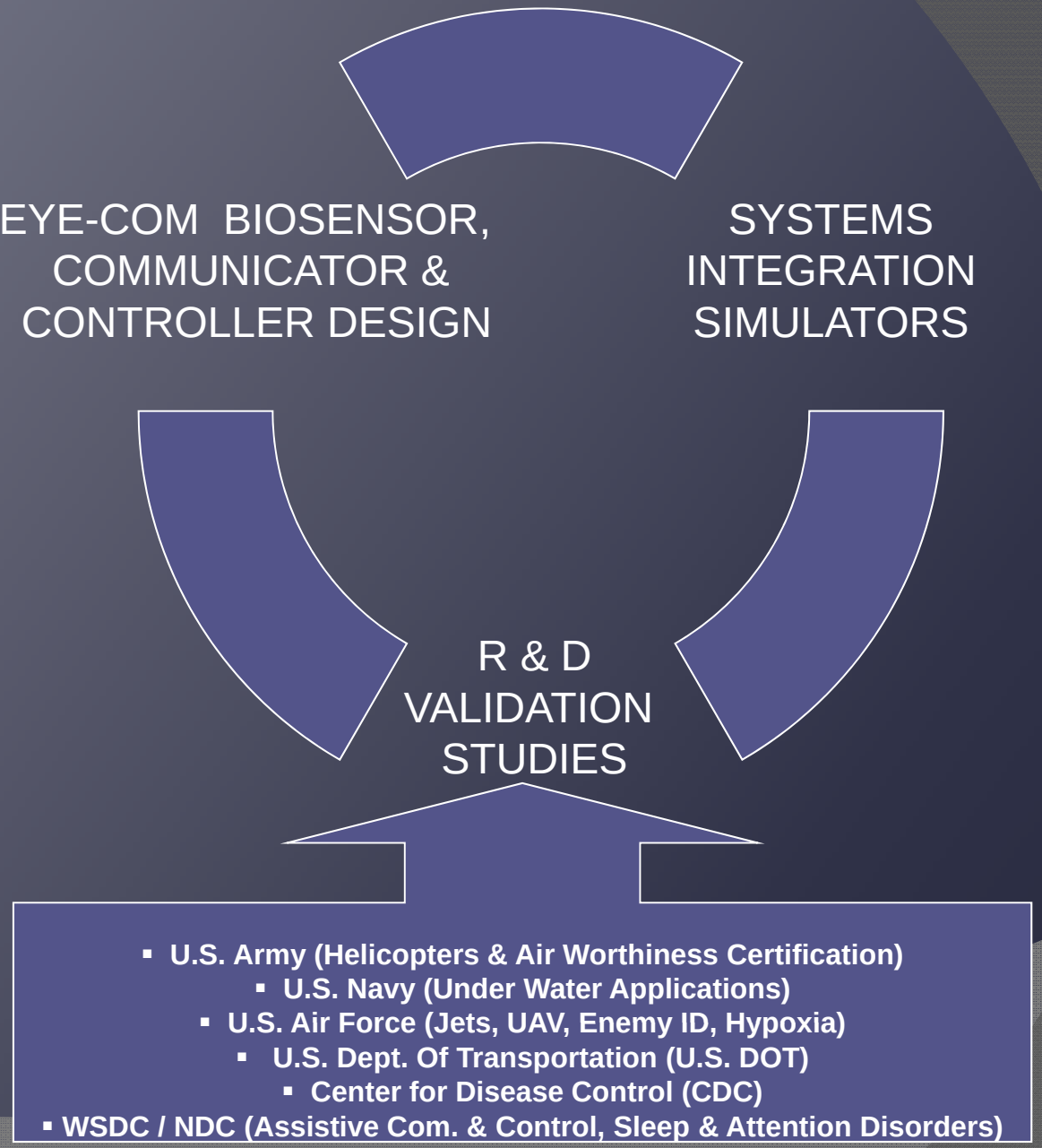


Was the accident the result of human factors? or machine error?

THERE IS A NEED FOR DROWSINESS OR INATTENTION DETECTION TECHNOLOGY TO:

- IDENTIFY OPERATORS AT RISK
- IDENTIFY LAPSES IN ATTENTION, DROWSINESS, AWARENESS OF ONE'S SURROUNDINGS, OR STATE OF SLEEPINESS
- IDENTIFY & RESPOND TO 1-3 SECOND MICRO-SLEEPS, EPISODES OF FALLING ASLEEP AT THE WHEEL , OR ANY LOC
- IDENTIFY DISTRACTION, INATTENTION OR LACK OF SITUATIONAL AWARENESS
- TAKE SOME PREVENTATIVE OR EVASIVE ACTION
- HELP DISTINGUISH HUMAN FACTORS FROM MACHINE ERROR AFTER THE FACT IN FATAL ACCIDENTS WITH NO SURVIVORS
- IDENTIFY EFFECT OF ILLICIT DRUGS & ALCOHOL

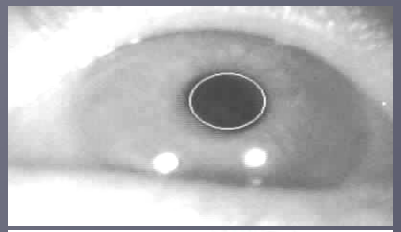
RESEARCH AND DEVELOPMENT STRUCTURE

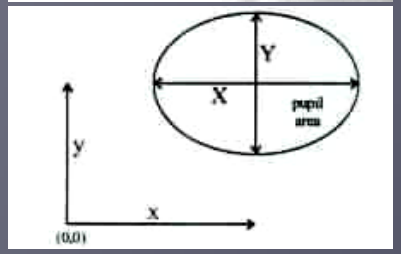


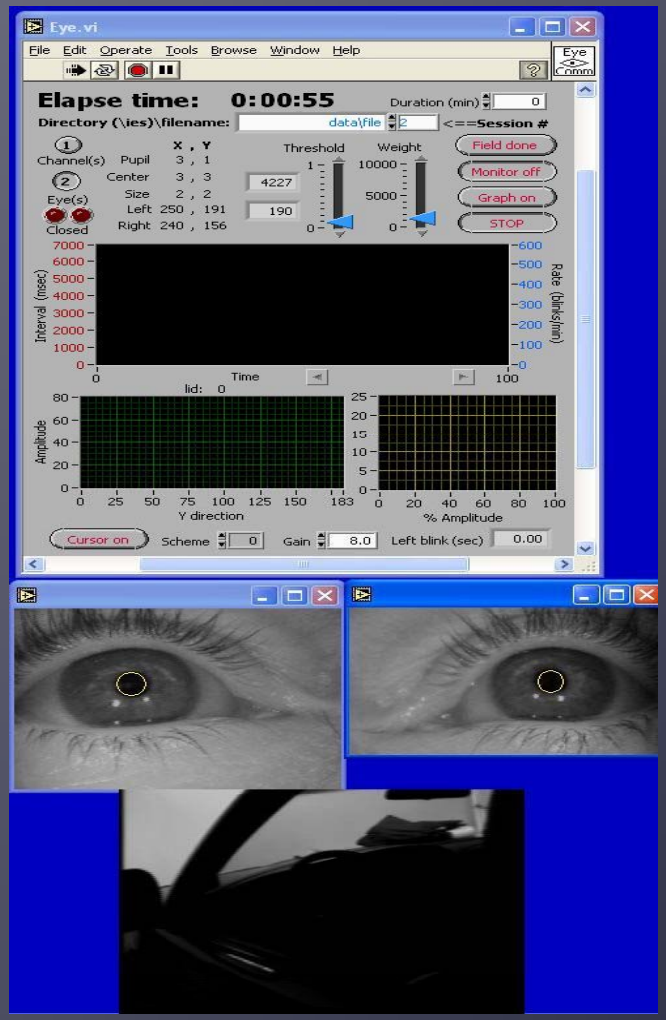
The previous Eye-Com® 6 (EC-6) Biosensor, is representative of a:

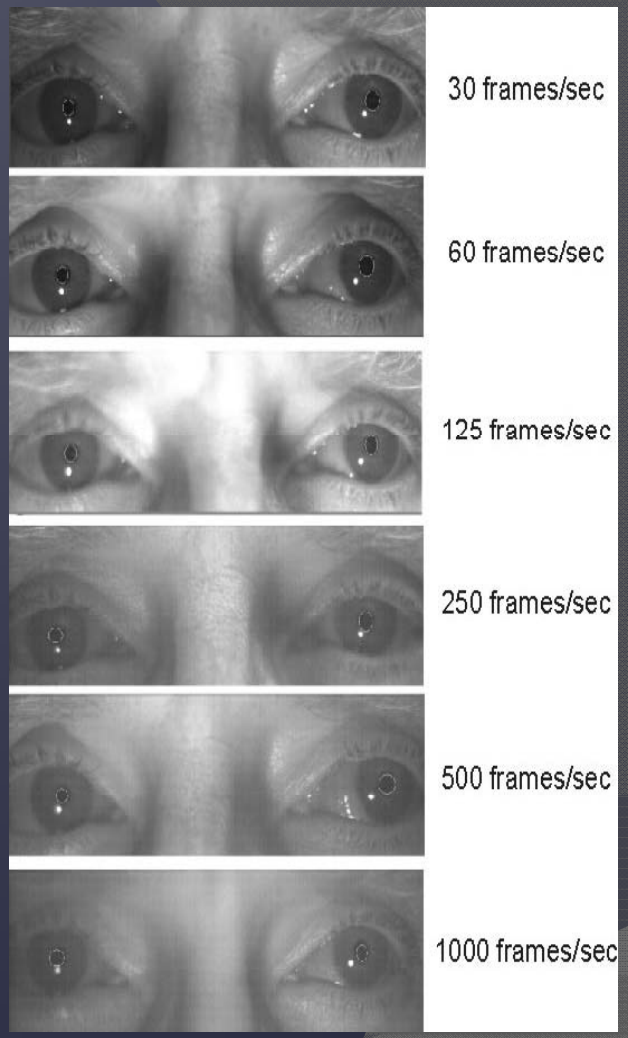
- Hybrid, in-vehicle, on-line operator status ocular monitoring technology
- Ambulatory, Wearable
- Real Time
- Automatic PERCLOS, EBD, EBF & other-Oculometric
- Biosensor, Communicator & Controller

The **EYE COM®™©** Biosensor, Communicator & Controller









EYE-SEE® SOFTWARE FOR OCULOMETRIC ACQUISITION MEASUREMENT & RECORDING

Acquisition rates of 30 to 1,000fps, depending on the application

OVER 30 OCULOMETRIC PARAMETERS COULD POTENTIALLY BE MEASURE *IN REAL-TIME* MONOCULARLY AND BINOCULARLY

THUS FAR, 16 PARAMETERS HAVE BEEN VALIDATED

EYE BALL POSITION

Pupil Center, X, Y direction (*)
Aggregate Fixation (*)

INTER-OCULAR DISTANCE

Separation Eyes Drift Measures

EYE BALL MOVEMENT

Pupil Center Velocity in X,Y direction (e.g. saccades)
Accumulated Pupil Center Movement
Pupil Distance from Mean Position
Eye Movement Frequency (EMF)
Pupil Center Overall Velocity (*)

DIRECTION OF EYEBALL MOVEMENT

Pupil Center Movement Direction (degrees/radians) (*)
Pupil Center Movement Direction From the Mean (*)
Eye Movement Patterns (contextual)
Dwell Time

EYE LID CLOSURE/OPENING

Eye Blink Duration (EBD) (*)
Eye Blink Frequency (EBF) (*)
Percentage of Time Eyelids Open/Closed (*)
PERCLOS (*)
Directional Eye Lid Velocity-up or down (ELV- Up/ELV-dn)
Eye blink flurries & patterns (contextual)
Directional Eye Lid Movement
Acceleration/ Deceleration ELA/D-up/ELA/D-dn)
Inter-Blink Duration (IBD)

PUPIL SIZE AND AREA

Pupil Radius/Diameter in X, Y direction (*)
Pupil Radius/Diameter, X, Y rates of change (*)
Pupil Area or Size (*)
Pupil Rates of Area change (Dilation/Constr.) (*)
Pupil Accumulated Area Changes (*)
Pupil Eccentricity (Y radius/X radius x 100%) (*)
Pupillary Appearance/Disappearance (*)

(*) Used in current validation studies

JOINT USDOT/USDOD STUDY

GOALS

- To validate oculometric measures as an index of operator impairment,
- To identify components that need to go into a reliable and objective Drowsiness Detection System,
- Design and develop a Composite Oculometric Fatigue Index (COFI)™ and a Safety Response (Eye-Com SAFE)™ Algorithm.

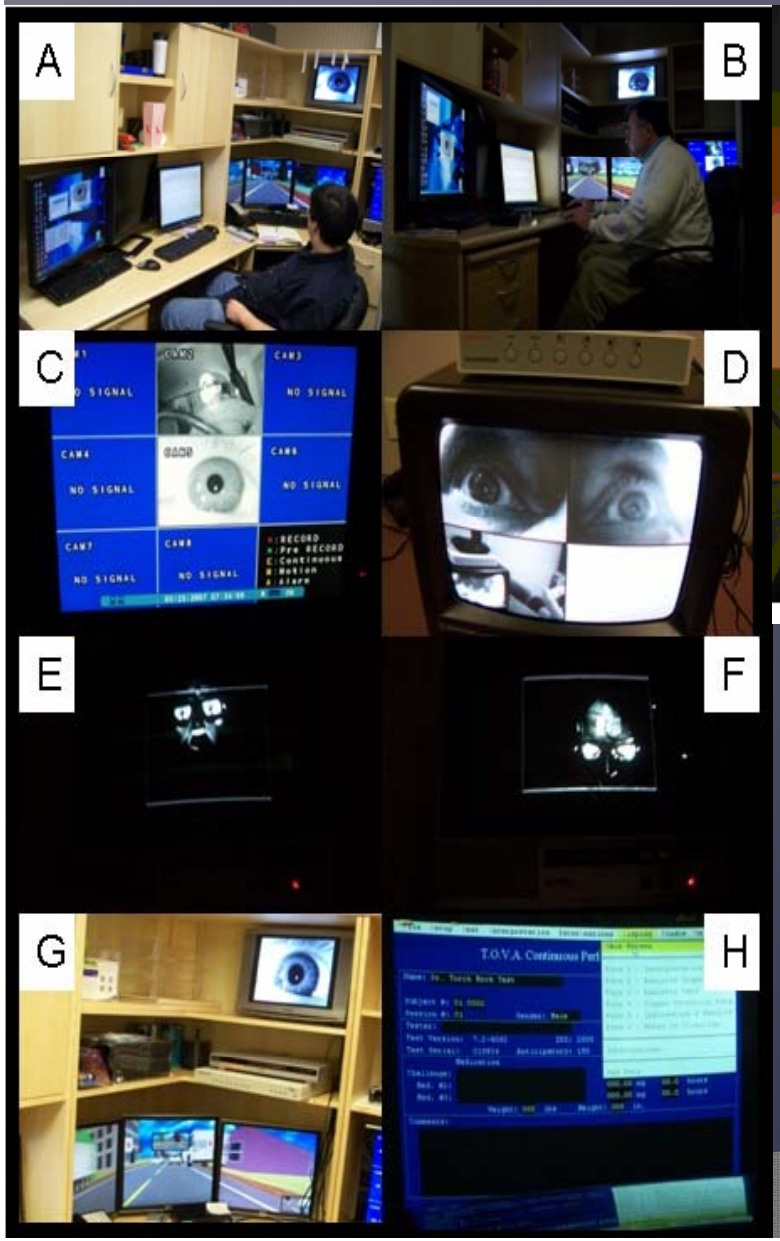
We have design a State-of-the-Art Laboratory to correlate several neurophysiological parameters with the Non-invasive, portable oculometric counterparts generated by the EC6

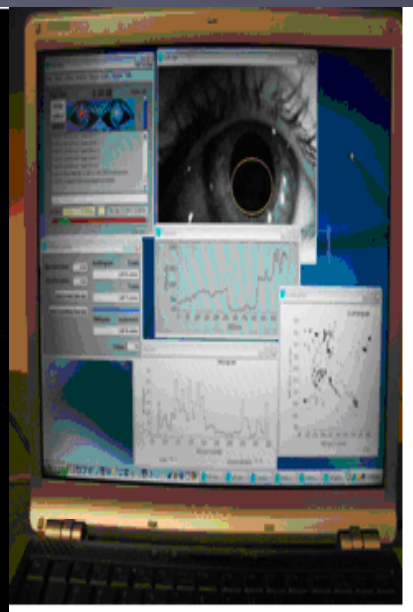
Eye-Com / STI Drive Simulator with performance synchronized to physiological measures

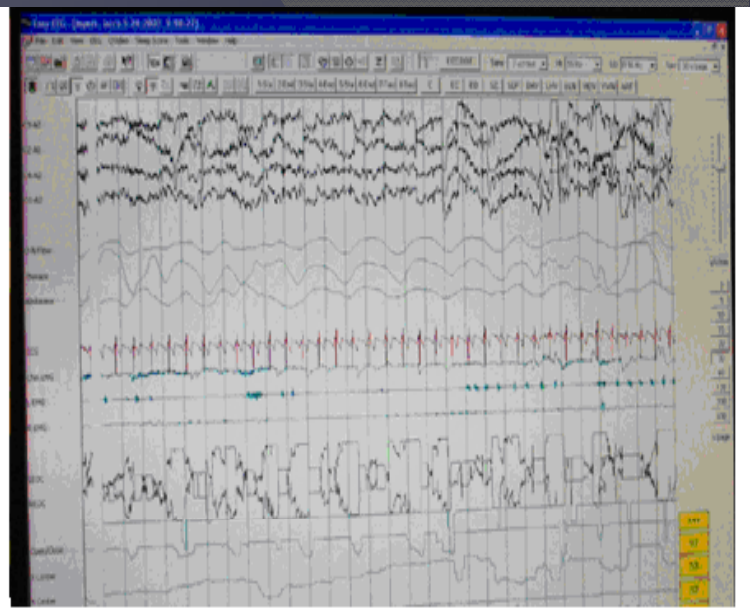
Test subject with EC-6, EEG, EKG, Heart Rate & Oxygen Levels

Test of Variable of Attention (TOVA) taken in the simulator right after the test drive session

Monitoring Station of the Eye-Com Simulation and Neurophysiology Laboratory







Synchronized integration of Eye-Com oculometric data with the car/truck drive simulator and other neurophysiologic parameters, including: EEG, EKG, Blood Pressure, Heart Rate, oxygen levels, EMG, movement and body position.

- Inclusion Criteria:
  - Drivers ages 16 to 70.
  - Male or Female.
  - Healthy or diagnosed with Sleep or Attention Deficit Disorders.

- Exclusion Criteria:
  - Cognitively impaired or legally incompetent.
  - Pregnancy.
  - Current use of sedative drugs or intoxicants.
  - Any condition considered by examining MD to be a health or safety risk.

DIAGNOSTIC GROUPS DETAIL

- CONTROL: Healthy subjects without sleep or attention deficit disorders based on normal clinical history, physical exam and special questionnaires.

- ADD/ADHD(*): Adolescent subjects of driving age with treated or untreated ADD or ADHD (e.g. stimulant therapy).

- SLEEP APNEA(*): Newly or previously diagnosed subjects with treated or untreated obstructive sleep apnea (e.g. Continuous Positive Airway Pressure –CPAP- or Biphasic Positive Airway Pressure –BIPAP-).

- NARCOLEPSY(*): Newly or previously diagnosed subjects with treated or untreated Narcolepsy (e.g. stimulant therapy).

(*) subjects under treatment discontinued their treatment during the study period.

PROCEDURES

Subjects enrolled in the study underwent six evaluation sessions spread over a thirty-four hour period.

ACTIVITY	DURATION (In minutes)	COMMENTS
ECC STI Drive Simulator Synchronized with ECC Oculomotor Assessment and Electroencephalography	Up to 40	The driving scenario is distance based. Thus depending on the speed, the task can take between 12 to 40 minutes.
Test of Variables of Attention (TOVA)	22.5	The test has an exact duration
Maintenance of Wakefulness Test (MWT)	Up to 40	The test ends whenever the subject falls asleep or after 40 minutes (whatever comes first).
Stanford Sleepiness Scale (SSS)	5	It may take between 1 and 5 minutes.

DATA ANALYSIS

- All data were tabulated from their source format into the Statistical Package for the Social Science (SPSS 14.0 version) data file format.

- Normality tests showed that the distribution of variables were normal across the diagnostic groups and sessions.

- To remove variability among subjects in same groups and to determine performance trends over the sleep deprivation cycle, a repeated measure analysis of variances (ANOVA) was carried out for all the relevant variables.

RESULTS

Detection of Session Effects (Drive Simulator)

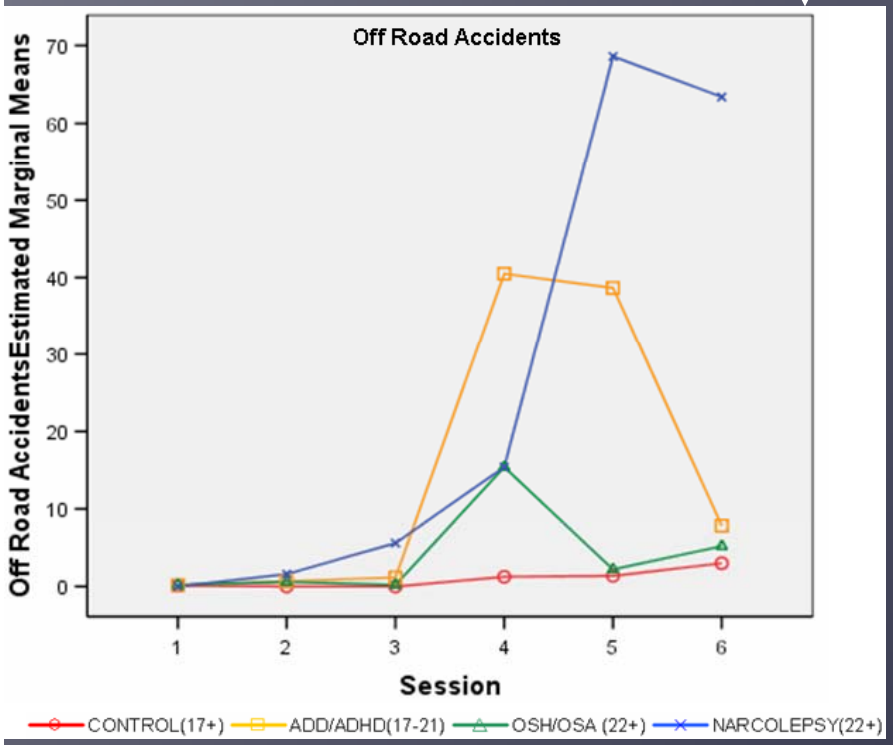
- Among the drive simulator variables, *Speed*, *Lane Position*, *Time Across Center Line*, and *Speed Exceedances* and *Center Line Crossing* failed to show significant diagnostic group or session effects.

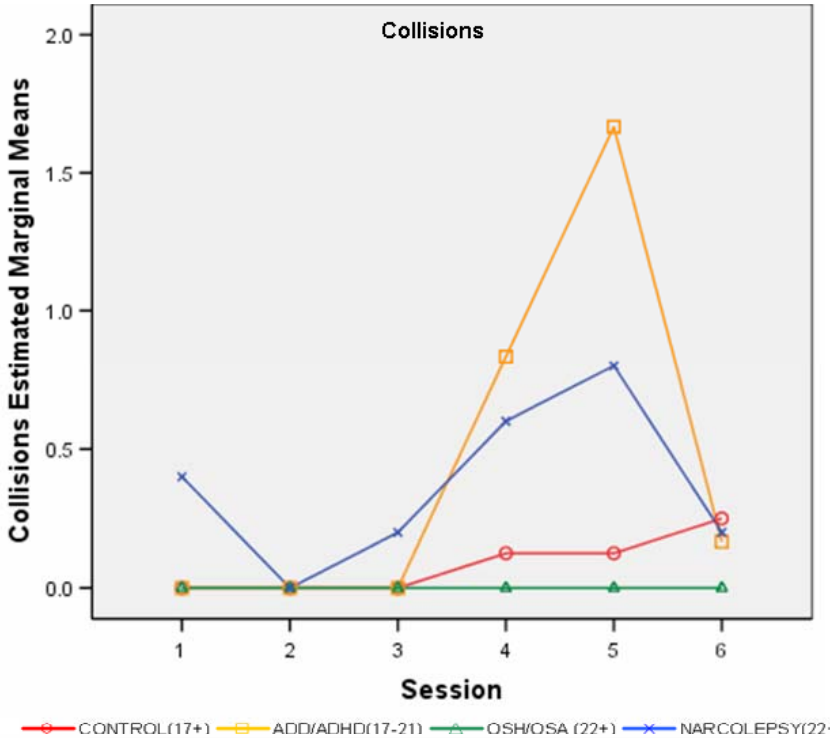
- The four diagnostic groups showed distinct changes during the drive simulator tasks in three variables with significant within- and between- subject effects.

- Session effects were all due to significant linear increases in the consecutive sessions.

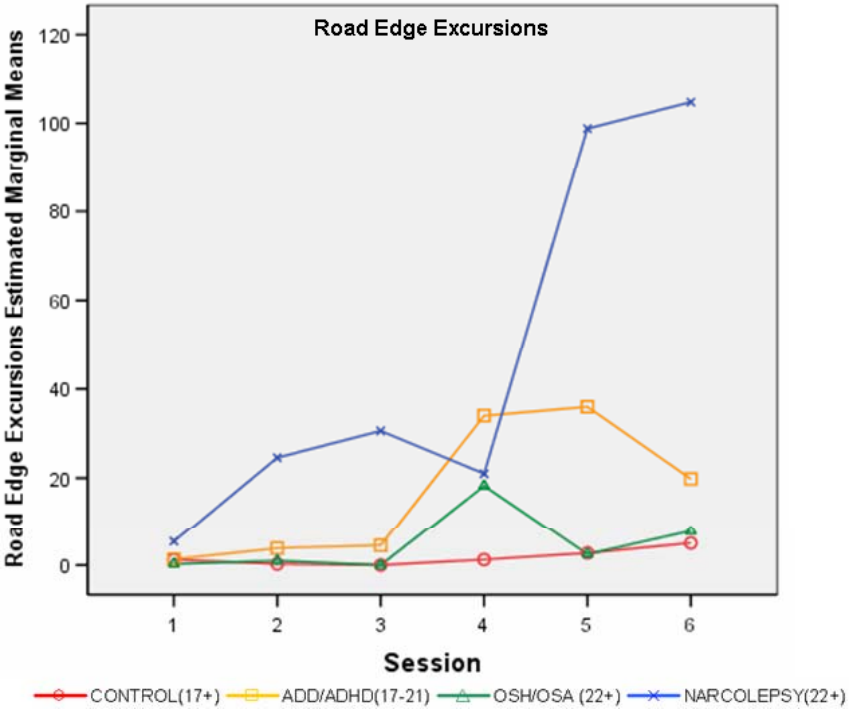
F(2.5, 50) = 3.953, p = 0.01

F(2.5, 50) = 6.389, p < 0.002





F(2.5, 50) = 7.325, p = 0.001



- Significant linear increases for consecutive sessions

Diagnostic-Group Effects

Off Road Accidents, $F(3, 20) = 4.53$, $p = 0.01$

Collisions, $F(3, 20) = 3.56$, $p = 0.03$

Road Edge Excursions, $F(3, 19) = 4.86$, $p = 0.01$

Least Significant Difference (LSD) post-hoc comparisons

- Significantly higher number of *Off Road Accidents* for the Narcolepsy group when compared to Control and OSH/OSA, and for the ADD/ADHD group when compared to control.
- Significantly higher number of *Collisions* for the ADD/ADHD group when compared to the Control and OSH/OSA, and narcoleptic subjects had significantly higher number of *Collisions* than subjects in the OSH/OSA group.
- Significantly higher number of *Road Edge Excursions* for the Narcolepsy group that those subjects in the Control, ADD/ADHD and OSH/OSA groups.

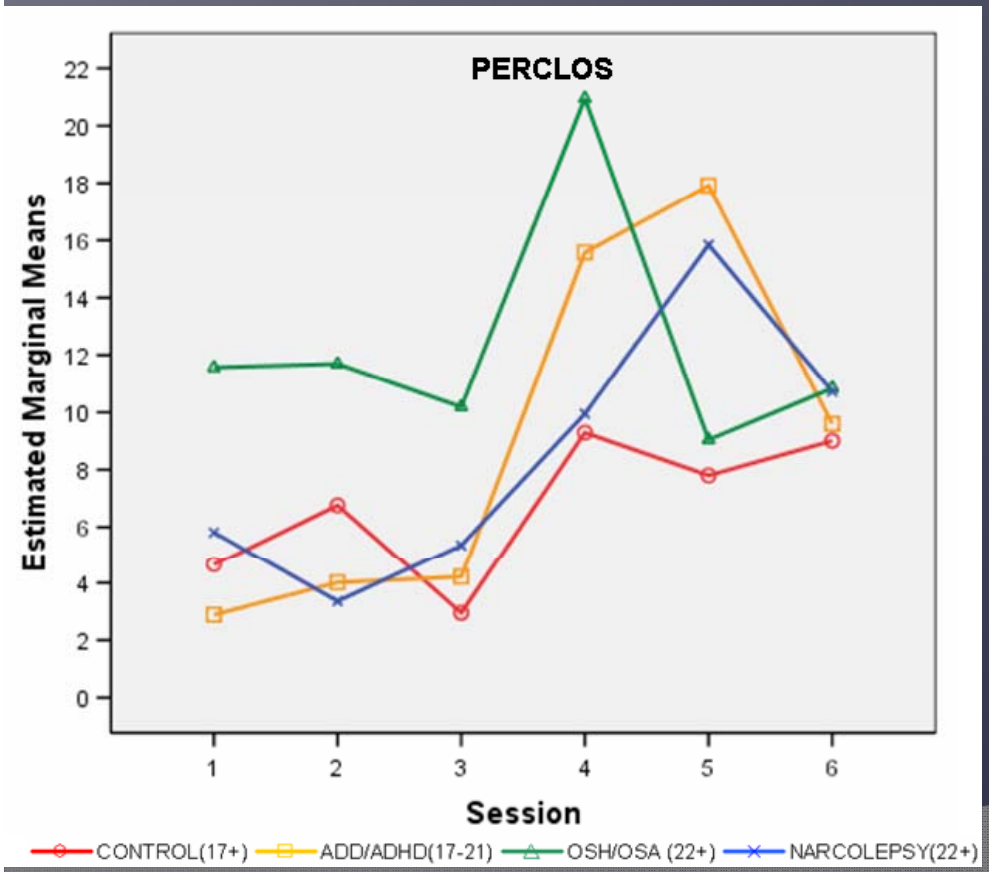
Detection of Session Effects (OCULOMETRICS)

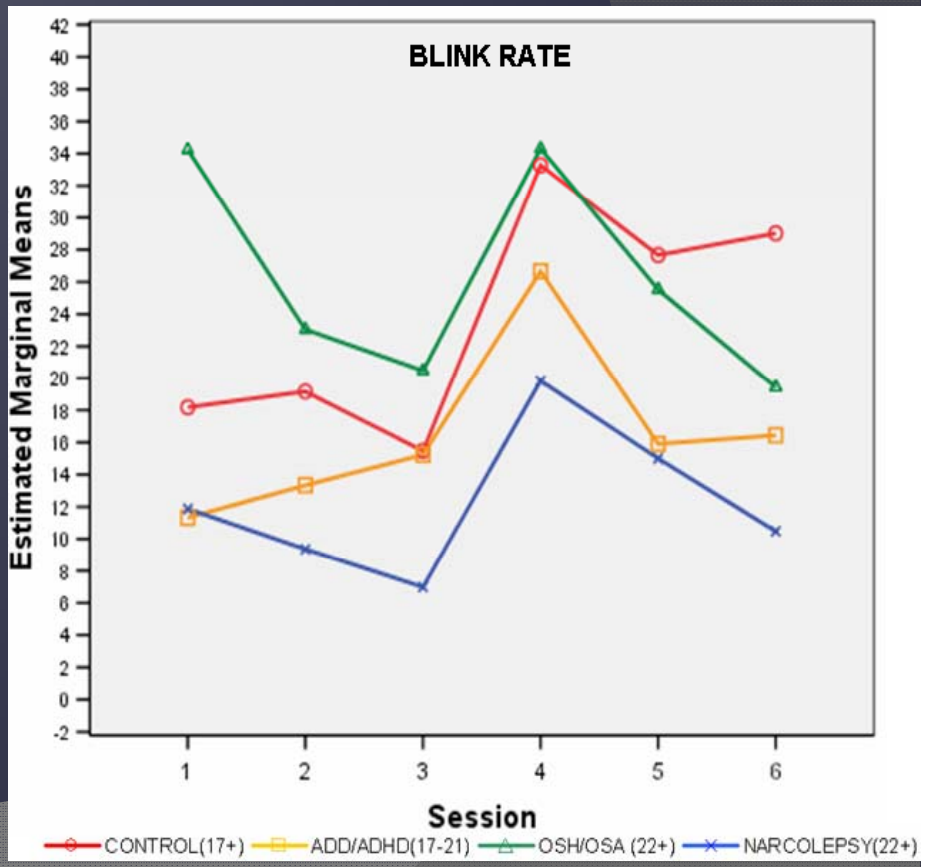
F(3.2, 72.5) = 7.467, p < 0.0001

(Linear)

F(2.6, 59.7) = 6.257, p = 0.002

(Linear & Cubic)

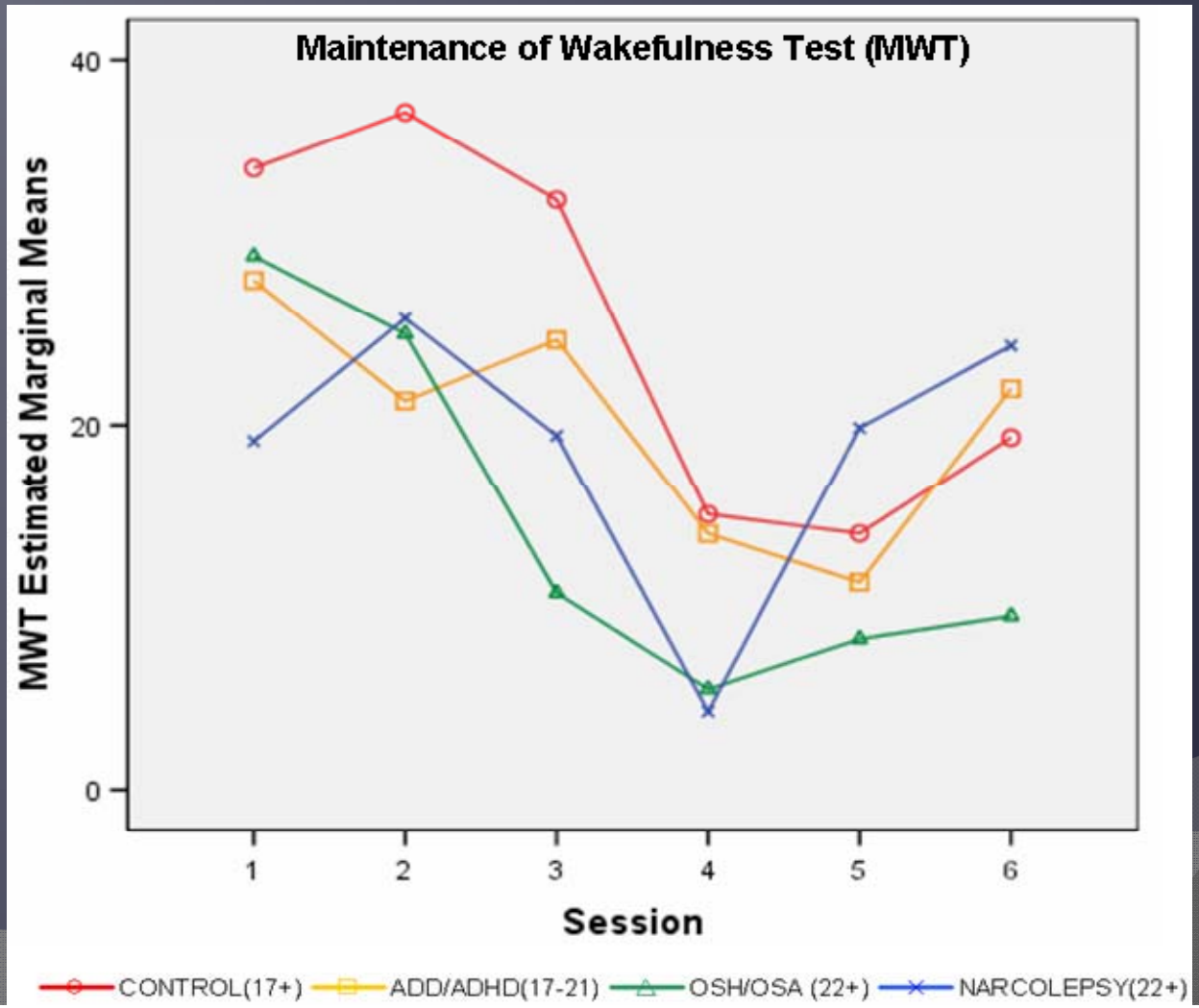




Detection of Session Effects (M W T)

F(3.3, 72) = 16.282, p < 0.0001

(Linear & Quadratic)



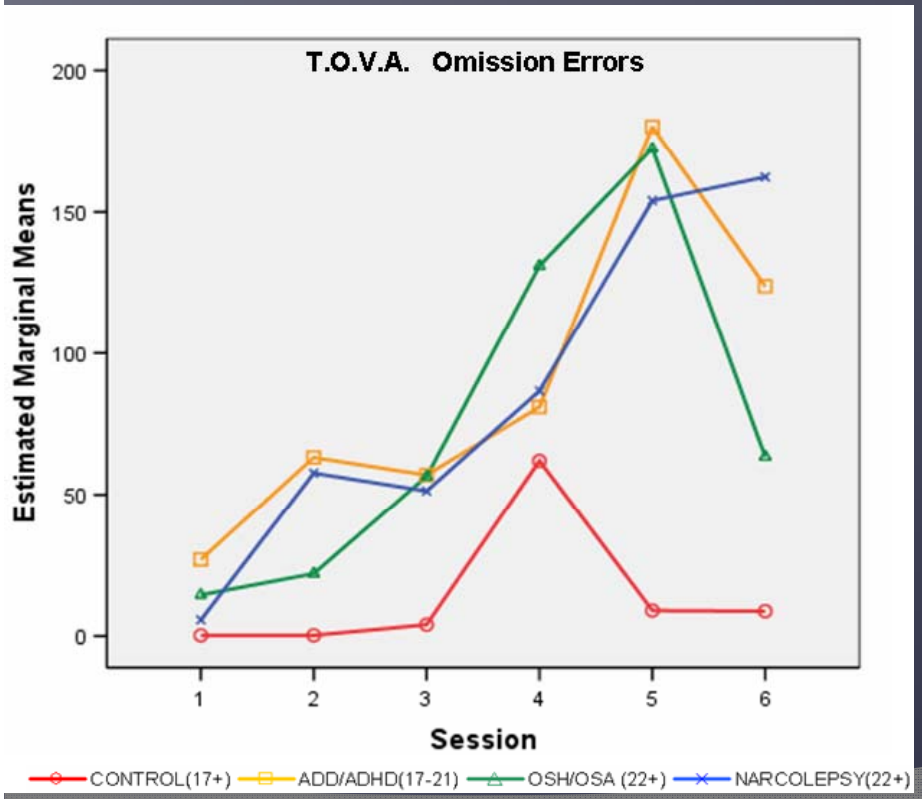
RESULTS

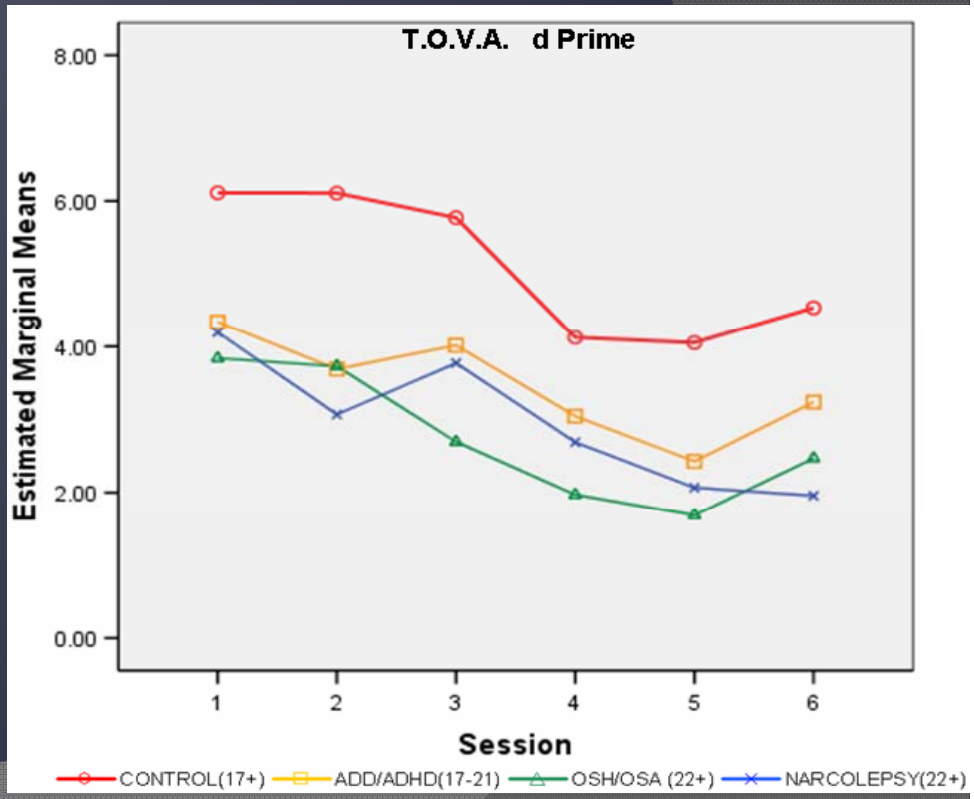
Detection of Session Effects (T O V A)

- *Reaction Time* and ***Reaction Time Variability***, ***Commission Errors*** and ***Anticipatory Responses*** showed no significant effects for both session and diagnostic groups.

F(2.8, 28.6) = 7.717, p = 0.001 (Linear)

F(5, 50) = 10.345, p < 0.0001 (Linear)





Oculometric Measures as Predictors of Driving Performance

- We performed Multiple Regression for predicting *Off Road Accidents*, *Collisions*, and *Road Edge Excursions* from PERCLOS, Blink Rate Pupil Area, and Age at each individual session.

- Session 4 had consist significant regressions with *PERCLOS* and *Blink Rate* accounting 54.2% of the variation in *Off Road Accidents*, 52.1% of the variation in *Road Edge Excursion*, and 32.7% of the variation in *Collisions*.

- Difference between the R square and Adjusted R square values for the three models suggest that *PERCLOS* and *Blink Rate* would also be good predictors if the models were derived from the population rather than our sample.

- Relatively large F-ratio for the models makes it very unlikely that these results are due to chance.

Oculometric Measures as Predictors of Driving Performance

Off Road Accidents	Session 4	Session 5
R^2 / Adjusted R^2	.542 / .489	.504 / .463
F Statistic	$F_{2, 29} = 14.89$	$F_{2, 26} = 12.20$
Significance	*P*<.0001	*P*<.0001
Predictor Variable Standardize Beta Significance Predictor Variable Standardize Beta Significance	PERCLOS .832 *P*<.0001 Blink Rate -.589 *P*=.001	PERCLOS .684 *P*<.0001 Blink Rate -.415 *P*=.01

Oculometric Measures as Predictors of Driving Performance

Road Edge Excursions	Session 4	Session 5
R^2 / Adjusted R^2	.521 / .485	
F Statistic	$F_{2, 29} = 14.67$	
Significance	*P*<.0001	
Predictor Variable Standardize Beta Significance Predictor Variable Standardize Beta Significance	PERCLOS .642 *P*<.002 Blink Rate -.600 *P*=.001	

Oculometric Measures as Predictors of Driving Performance

Collisions	**Session 4**	**Session 5**
R^2 / Adjusted R^2	.327 / .277	.170 / .137
F Statistic	$F_{2, 29} = 6.56$	$F_{1, 26} = 5.14$
Significance	*P*=.005	*P*<.03
Predictor Variable Standardize Beta Significance **Predictor Variable** Standardize Beta Significance	**PERCLOS** .642 *P*<.002 **Blink Rate** -.503 *P*=.01	**PERCLOS** .412 *P*<.03

Oculometric Measures as Predictors of Driving Performance

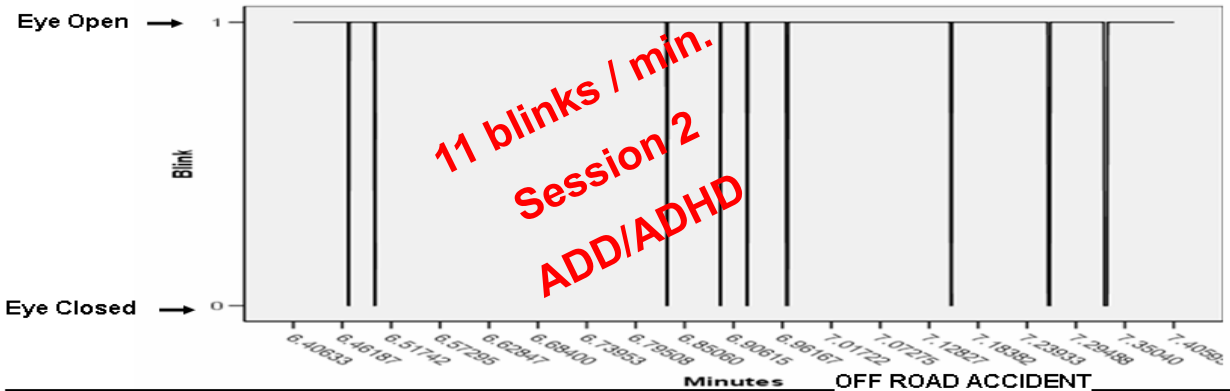
- We averaged Accident Events into a new Driving *Simulator Performance* variable, and a new regression analysis showed improved coefficient of determination, which translates into a higher reduction in error variability associated with the regression model.

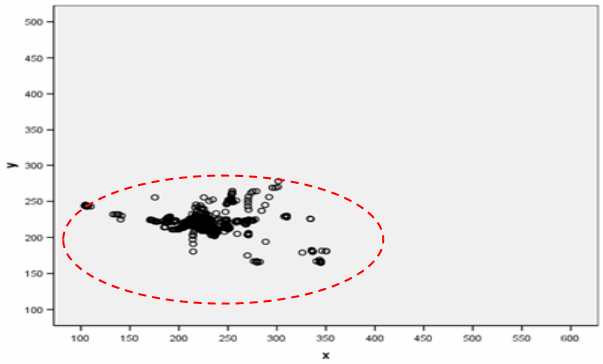
- As a consequence, PERCLOS and Blink Rate account for an even higher percentage of variation in the new driving simulator performance variable at:

  - Session 4 [R-square = .579], $F(2, 29)= 18.53$, $p<0.0001$
  - Session 5; [R-square = .424], $F(2, 26)= 8.83$, $p=0.001$.

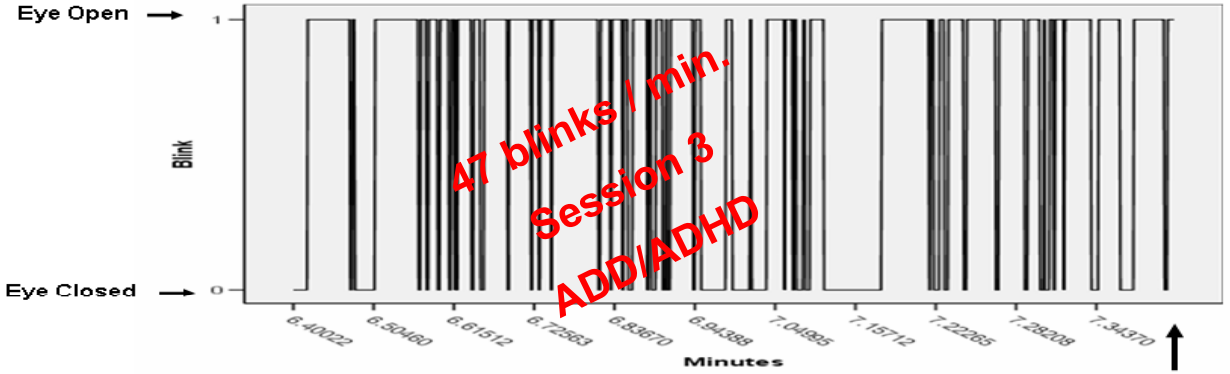
COMPARISON OF NO ACCIDENT VS. AN ACCIDENT EVENT WHILE NOT SLEEP DEPRIVED

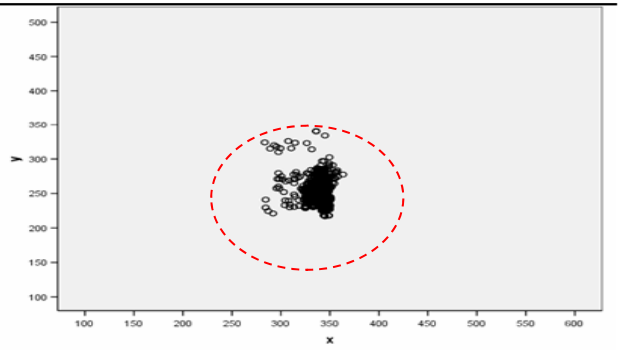
NO ACCIDENT



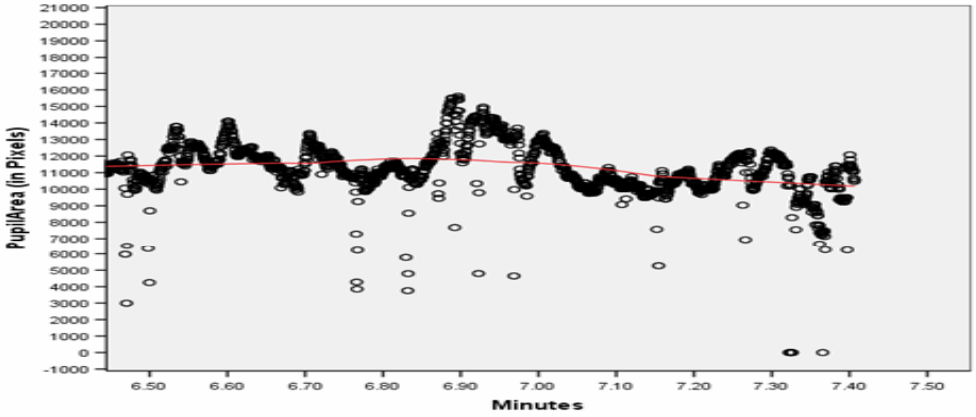


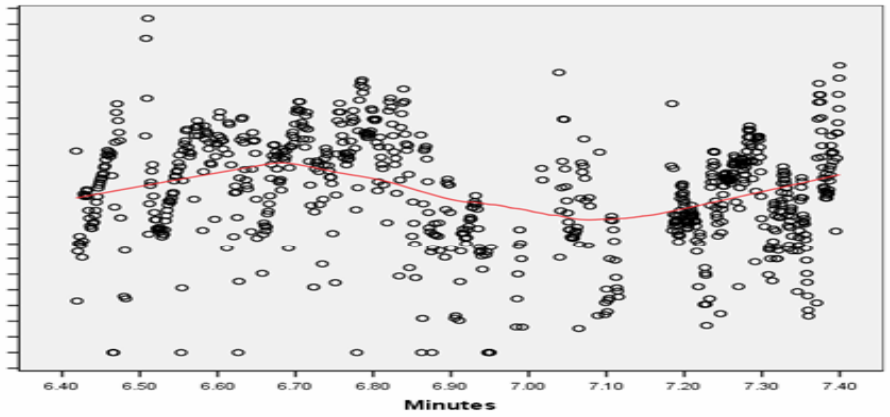
OFF ROAD ACCIDENT



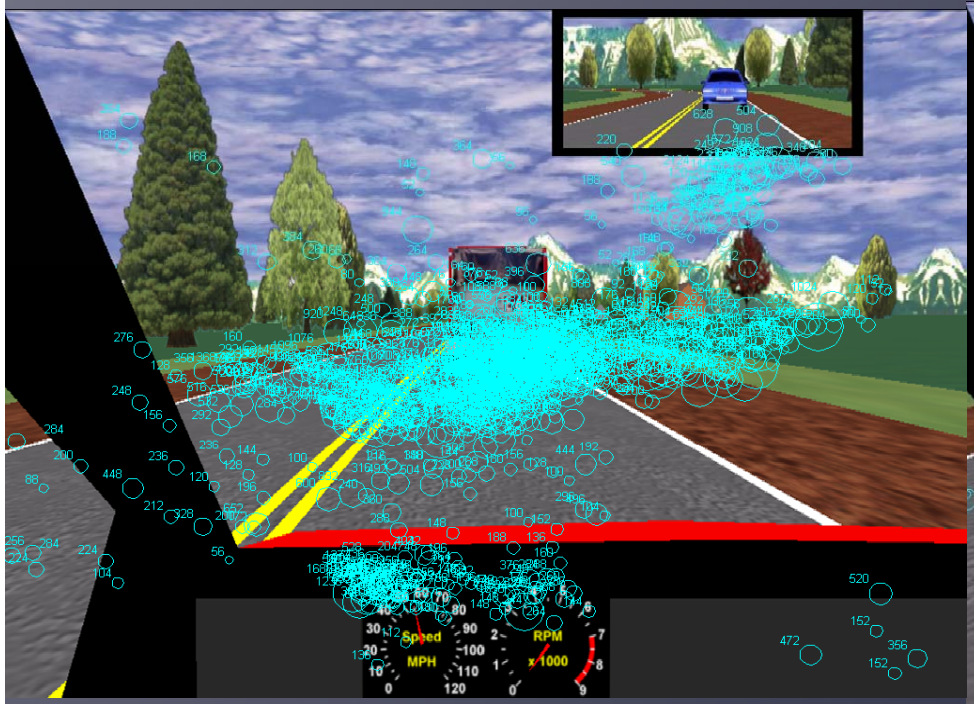


Time When Accident Occur

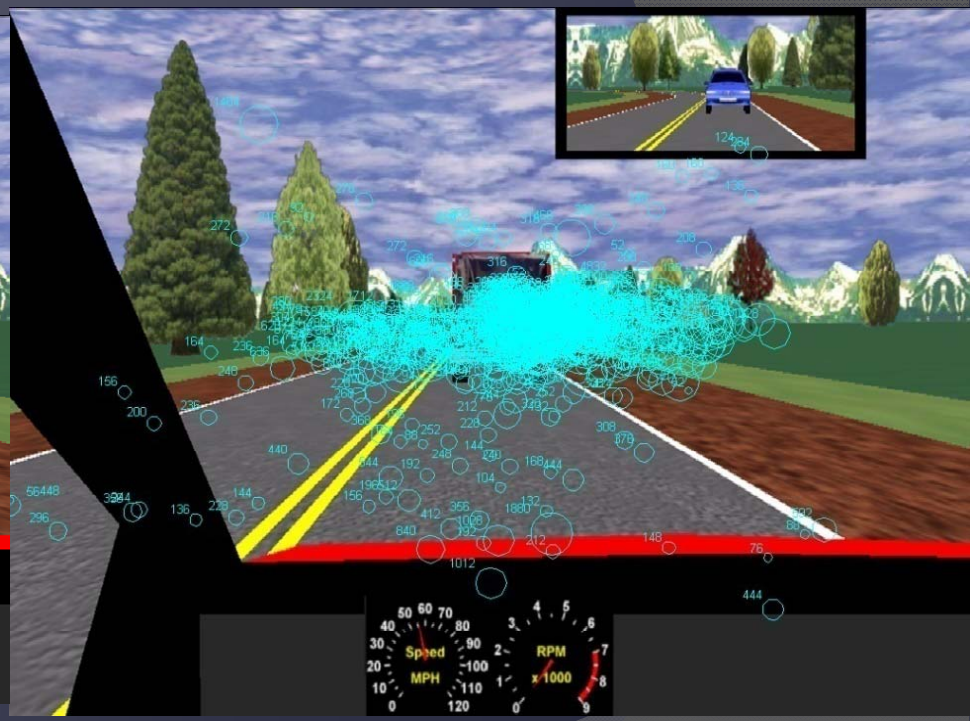




Aggregated Ocular Fixation as an Indicator of Driver Distraction



NORMAL



DISTRACTED

SUMMARY

- Significant trends over time (STISIM, Oculometrics, MWT, TOVA) confirming sleep deprivation effects.
- PERCLOS and EBD and Pupil Size may be good indicators of drivers drowsiness.
- Aggregate eye gaze, EBF and Pupil Size may be good indicators of driver distraction or inattention.
- *Pupil Area* for individual subjects as well group averages, showed a tendency to decrease as a function of both time-on-task and sessions.
- The decrease in pupil diameter was not enough to show significance but individual evaluations of the pupil area before accident events showed that some valuable predictive information might be extracted using this oculometric parameter.

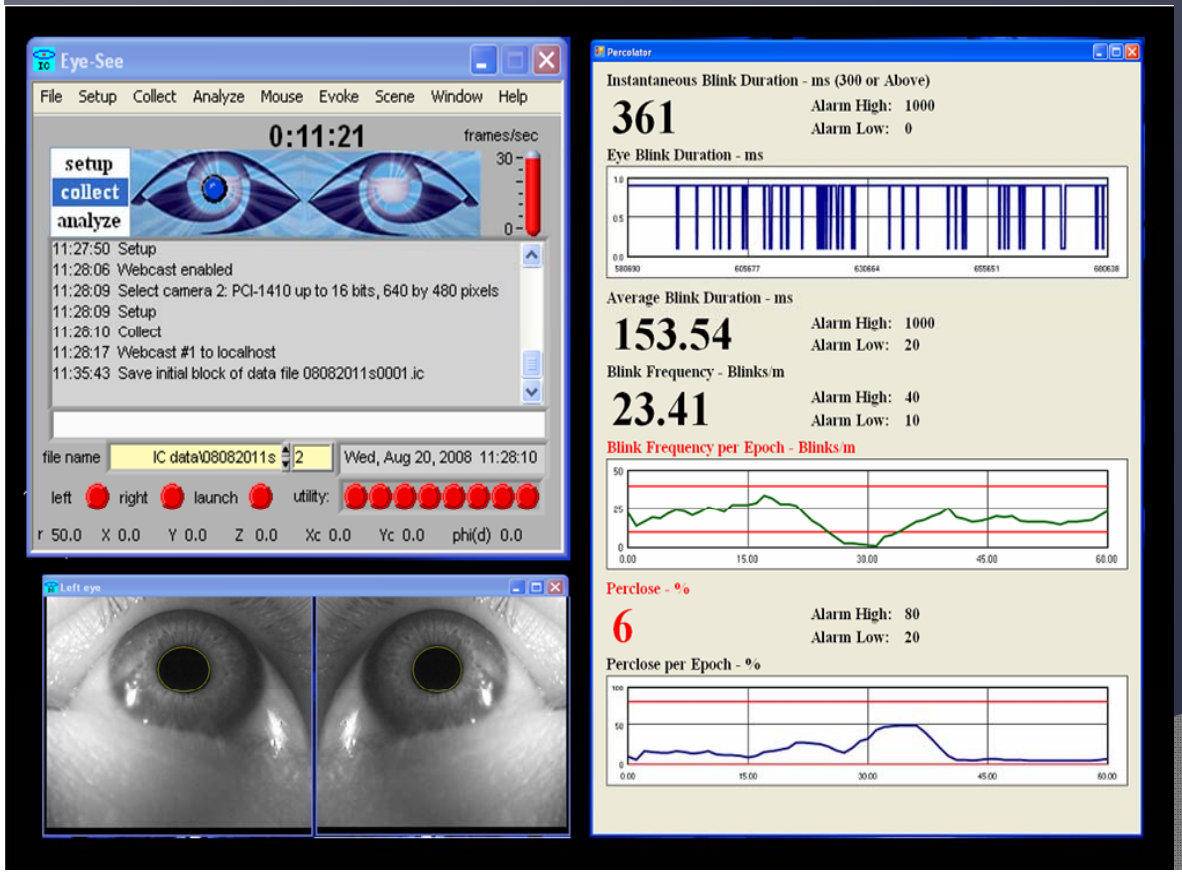
BASED ON THIS, AND PREVIOUS VALIDATION STUDIES WE DEVELOPED:

- An Eye-Com 6 system integrated to an on-line, real-time PERCLOS/EBD/EBF GUI-software that is being tested as the basis for the Eye-Com Composite Oculometric Fatigue Index (COFI)™ and Safety Response (Eye-Com SAFE)™ Algorithms currently under development.

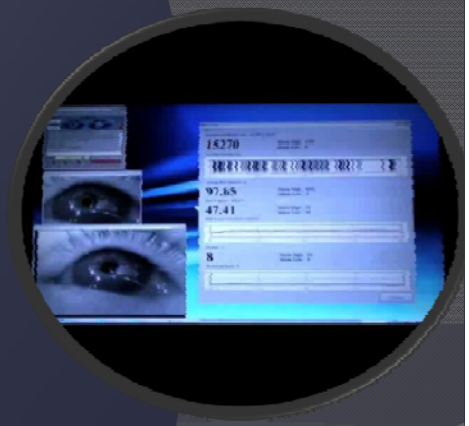
- The Eye-Com 6 and the GUI software were fully integrated in a Smart Car for testing on the road (real-life scenarios, under different lightning and weather conditions which eventually will be compared to simulation outcomes).

REAL-TIME OCULOMETRICPERCLOS, EBD, EBF MEASURES

The GUI software can be configured, as-needed, to display oculometric and other bio-physiologic measures for any desired epoch duration (seconds or minutes), on a sliding scale basis, and its oculometric parameters can be displayed along with visible or audible warnings based on very specific upper and lower threshold range and limit settings.



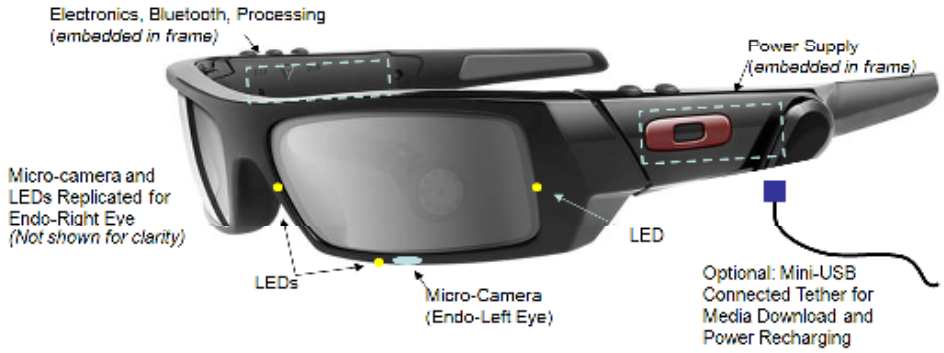
GUI CLIP



Smart Car CLIP

NEW EYE-COM 7/8

Evolution of EC



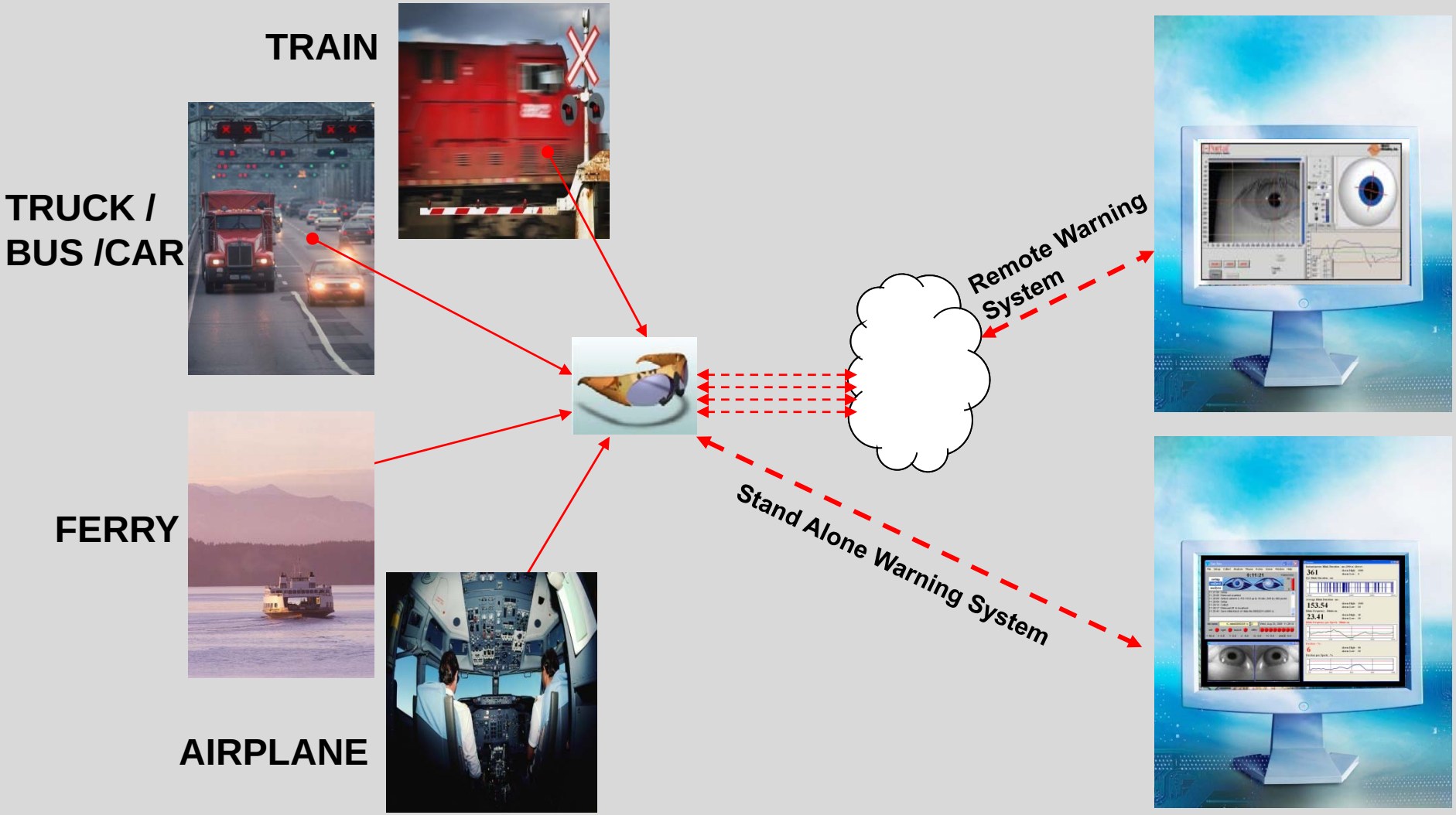
EC7- Eye-tracking, BT, Battery power

EC8- EC7 + Gaze tracking w/ LED tracking

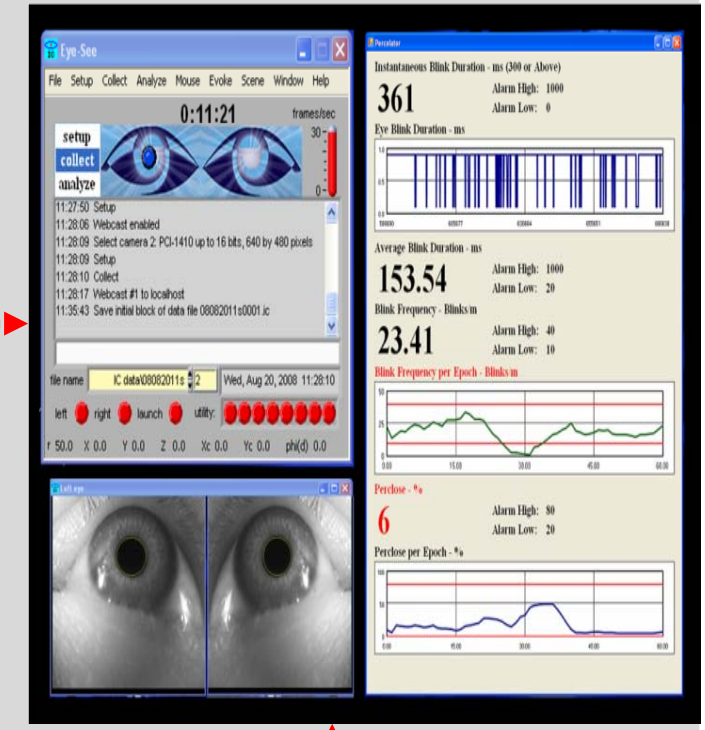
EC9- EC8 + USB, EEG, Upgraded Memory

- ✓ ERGONOMICALLY DESIGNED
- ✓ WIRELESS (BLUE TOOTH)
- ✓ REAL TIME & AUTOMATIC
- ✓ TOTALLY SYSTEMS INTEGRATED
- ✓ FPGA & SELF-CONTAINED ELECTRONICS
- ✓ COFI & COFI SAFETY RESPONSE
- ✓ FOR ALL DOMAINS & ENVIRONMENTS

Fatigue, Inattention, Distraction, Detection of Alcohol/Substance/Drug Effect, and Accident Prevention in General Transportation



Fitness-for-Driving Assessment
(Elderly, Teens, Sleep and Cognition Performance Evaluation)



QUESTIONS ?

William Torch: btorch@eyecomworld.com

Carlos Cardillo ccardillo@eyecomworld.com

Eye-Com Corporation
75 Pringle Way, Suite 906
Reno, NV 89502 USA
Tel.: 775.329.2006
www.eyecomworld.com