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TECHNOLOGIES FOR THE MONITORING AND PREVENTION OF DRIVER FATIGUE

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Summary: A series of driving simulation pilot studies on various technologies for alertness monitoring (head position sensor, eye-gaze system), fitness-for-duty testing (two pupil-based systems), and alertness promotion (in-seat vibration system) has been conducted in Circadian Technologies' Alertness Testbed. The results indicate that, all tested technologies show promise for monitoring/testing or preventing driver fatigue, respectively. However, particularly for fatigue monitoring, no single measure alone may be sensitive and reliable enough to quantify driver fatigue. Since alertness is a complex phenomenon, a multi-parametric approach needs to be used. Such a multi-sensor approach imposes challenges for online data interpretation. We suggest using a neural-fuzzy hybrid system for the automatic assessment of complex data streams for driver fatigue. The final system output can then be used to trigger the activation of alertness countermeasures.

INTRODUCTION

Driver fatigue has become acknowledged as the most significant safety hazard in the transportation industry. This has stimulated an extensive international research program on driver fatigue causes and countermeasures. A recent comprehensive analysis of the world's literature shows the emphasis is moving from investigations of causes to studies of specific countermeasures. Before 1993 only 20% of published work was on countermeasures, but now the balance has changed with 63% of current projects focusing on countermeasures. This driver fatigue literature database has recently been compiled and made publicly available and searchable on the Internet by Circadian Technologies (www.circadian.com).

The most active area of research has become the development and validation of technological tools for measuring and preventing driver fatigue. Circadian Technologies has established a Driver Alertness Testbed for testing, validating and refining such technological tools (see below for details). A series of pilot studies on various technologies for measuring and preventing fatigue has been conducted, and a representative cross-section of the results will be presented here.

METHODS

The Tested Driver Fatigue Technologies

Alertness-monitoring technologies. Two potential alertness-monitoring technologies were tested: a head position sensor system (Figure 1) and an eye-gaze system (Figure 2). The head position sensor system **MINDS**TM (Advanced Safety Concepts, Inc.) is conceptually designed to detect microsleep events occurring in association with head nodding by assessing the x, y, and z coordinates of the head through conductivity measurements. The **Eye-Gaze** system (LC

Technologies, Inc.) originally developed for the eye-controlled operation of computer systems, uses a pupil center corneal reflection method to determine the x/y/z-direction of the eye's gaze and, in addition, provides information regarding pupil diameter, blinking, and eye fixation.

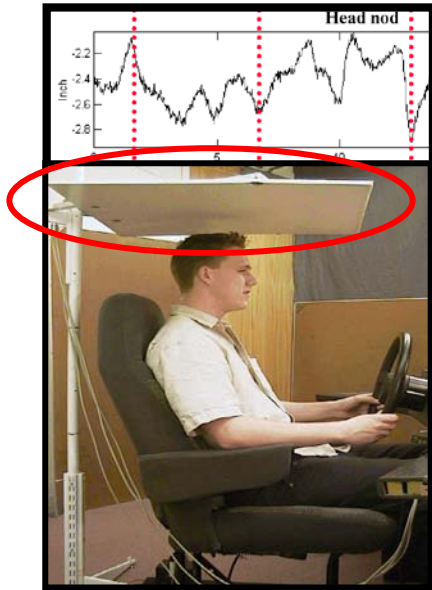


Figure 1: MINDS™ Head Position System

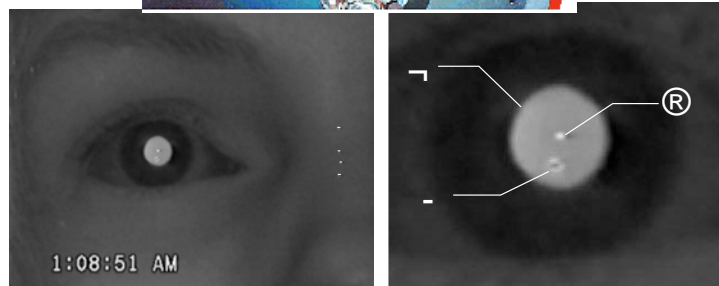


Figure 2: Eye-Gaze System. Reflection Eye Background (1), Cornea (2) and Fovea (3)

Fitness-for-duty technologies. Two potential fitness-for-duty systems were tested. Both systems use pupillometric measures (Figures 3 and 4). **SafetyScope™** (Eye Dynamics, Inc.), originally designed for alcohol and drug testing, uses a 90-second test to record pupil diameter and eye movement parameters while the test person fixates on a light displayed in the device. The test results are compared to the individual's baseline and classified into the categories passed, failed and invalid. The **Mayo Pupillometry System**, originally developed for the clinical assessment of narcoleptic patients, uses a 15-minute pupillogram recording to compute parameters of hippus (rhythmic dilation and contraction of the pupil), miosis (pupil constriction) and blink rate.



Figure 3: SafetyScope™ System



Figure 4: Mayo Pupillometry System

Fatigue countermeasure technologies. An in-seat vibration system was tested as a potential driver fatigue countermeasure. This TACT™ technology (InSeat Solutions, LLC) was applied in two different delivery modes: random signal and triggered signal (initiated online by the experimenter based on behavioral sleepiness signs such as prolonged eye closures).

The CTI Alertness Testbed

Circadian Technologies’ Alertness Testbed uses a multi-parametric approach including performance measures in driving simulator and other vigilance tasks, physiological sleepiness measures (EEG microsleeep events), behavioral signs of sleepiness (e.g., prolonged eye closures, multiple blinks, head nodding, yawning etc.), and subjective sleepiness measures (e.g., Visual Analog Sleepiness Scales, Thayer Activation-Deactivation Checklist). Typically, the driver alertness testbed is used to simulate driver fatigue in overnight protocols with sleep deprived volunteers motivated by payments for safe driving performance. Volunteers participate in a series of test sessions with each session including a 30-50 minute driving task and other performance and alertness tests. Electrophysiological signals (four EEG channels, two EOG channels, EMG, ECG) are continuously recorded throughout the experiment, and the subject’s face is video-taped during each driving session. Table 1 summarizes the test protocols and subject information for the pilot studies.

Pilot Study	Experimental Time Period	Number of Test Sessions Per Experiment	Subjects
MINDS™	2200-0900	8	4 (25-32 years)
Eyegaze	0100-0800	7	11(20-34 years)
SafetyScope™	1400-0700	9	6 (22-33 years)
Mayo Pupillometry System	1000-1100	13	5 (25-32 years)
TACT™ - I	0100-0800	7	3 (21-28 years)
TACT™ - II	2200-0900	8	3 test nights per subject 4 (25-32 years)

Table 1: Test Protocols and Subject Information for the Pilot Studies.

RESULTS

MINDS™ Head Position Sensor Study

Comparisons between the MINDS data and simultaneous video recordings showed that head nodding is clearly visible in the MINDS data. Figure 5 illustrates a raw data example for a period including an EEG microsleeep event characterized by increased activity in the EEG alpha band 8-12.5 Hz. The microsleeep was preceded by three head nod events, and followed by a crash in the driving simulation task. However, microsleeeps also occurred in the absence of obvious head nodding.

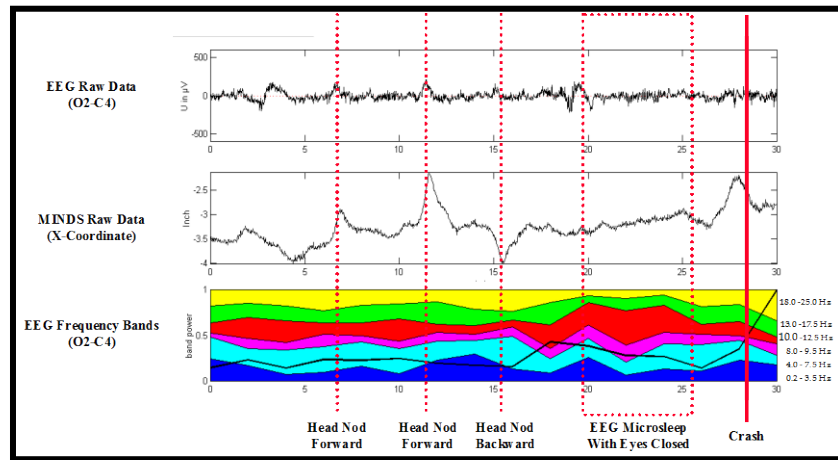


Figure 5: EEG and MINDS data example of one test subject for a 30-second period at 06:42.

Eye-Gaze Study

Eye-gaze data appears to contain information about microsleep events several seconds before the real event takes place. Figure 6 illustrates a recording that includes a microsleep event. Approximately 10 seconds before the microsleep event occurs, the pupil diameter shows a slowly fluctuating pattern correlated to no change (blank stare) in the eye-gaze coordinates. Closer to the microsleep event the pupil diameter decreases and the eye-gaze coordinates are drifting until the eyes are closed. Especially interesting is the behavior of the eye after the second eye closure event, which was cut short by an accident. Immediately after the accident, a sharp increase in the pupil diameter occurred in connection with rapid oscillations in the eye-gaze coordinates. This is the typical pattern for a person who is suddenly aroused by the accident and tries to re-orient himself.

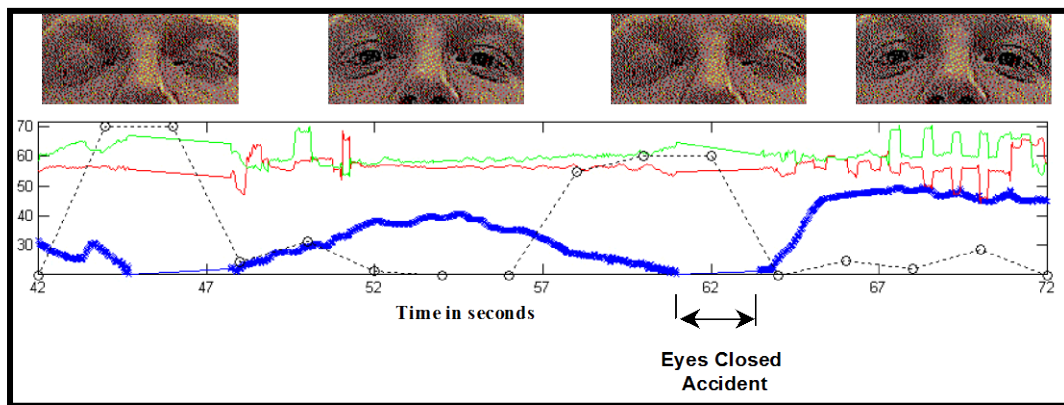


Figure 6: Eye-Gaze data for a microsleep event causing prolonged eye closure of approximately 6 seconds. The thick solid line represents the pupil diameter, the thin solid lines represent horizontal and vertical eye coordinate as a function of time. The dotted line shows the response of a Neural-Fuzzy Hybrid system for the automatic detection of microsleep events.

SafetyScope™ Study

SafetyScope™ indicated non-passed test results particularly at nighttime when the highest sleepiness levels occurred. 100% of the non-passed tests occurred either at night or during the mid-afternoon alertness dip. For the 2400-0700 nighttime window, the percentage of non-passed tests (relative to the total number of tests) was 25 %, which corresponds to the tests of the sleepest subjects. Results for SafetyScope and one Alertness Testbed parameter of one individual are shown in Figure 7.

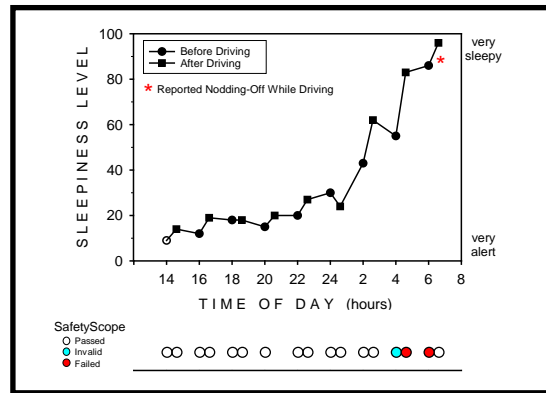


Figure 7: Subjective sleepiness (Visual Analog Sleepiness Scale) and SafetyScope results for one individual.

Mayo Pupillometry Study

Mayo pupillometric measures for miosis, hippus and blink rate reflected the circadian fluctuations (correlation analysis) found in the Alertness Testbed measures such as subjective alertness, driving performance, vigilance performance, and behavioral signs of sleepiness – showing clearly increased sleepiness levels at nighttime (see Figure 8). However, correlations between pupil parameters and microsleep events during the pupil test appeared to be rather weak.

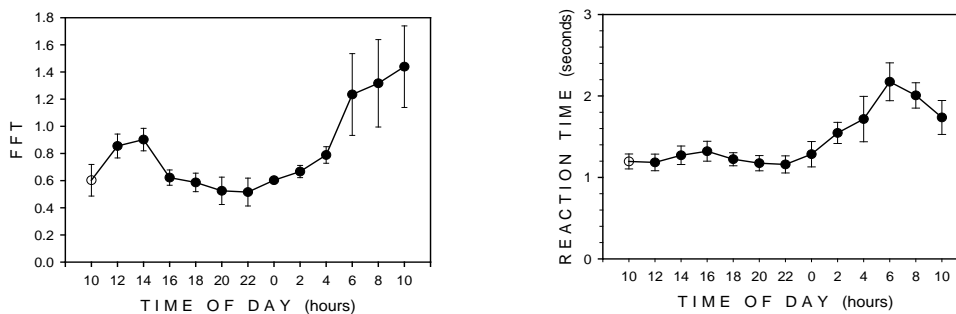


Figure 8: Circadian time course for group averages of one Mayo pupillometry parameter (miosis) (left) and one driving performance parameter (right)

TACT™ study

The pilot studies suggested that vibro-tactile stimulation using the TACT system holds promise as an effective way to help drivers stay awake. This was reflected in various Alertness Testbed

parameters. For example, head nodding – indicating severe sleepiness – was considerably reduced during driving sessions with TACT signal as compared to subsequent non-TACT sessions (Figure 9). The TACT system tended to be most effective at intermediate sleepiness levels. No over-reactive steering corrections were observed after TACT onset.

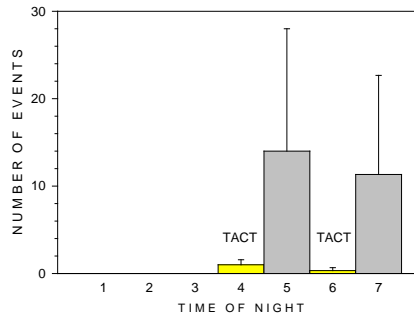


Figure 9: Number of head nodding events during simulated driving at nighttime with (test sessions 4 and 6) and without TACT seat vibration (test sessions 1-3, 5 and 7).

CONCLUSIONS

The results of the various driving simulation pilot studies indicated that, all tested technologies show promise for monitoring/testing or preventing driver fatigue, respectively. However, particularly for fatigue monitoring, no single measure alone may be sensitive and reliable enough to quantify driver fatigue. Since alertness is a complex phenomenon, a multi-parametric approach needs to be used. Such a multi-sensor approach imposes challenges for online data interpretation. We suggest using a neural-fuzzy hybrid system for the automatic assessment of complex data streams for driver fatigue. The final system output can then be used to trigger the activation of alertness countermeasures.