

The mission of the Office of Motor Carrier and Highway Safety is to develop and promote, in coordination with other Departmental modes, data-driven, analysis-based, and innovative programs to achieve continuous safety improvements in the Nation's highway system, intermodal connections, and motor carrier operations. The Office of Motor Carrier Research and Standards manages the safety regulatory program and the central research management function for Motor Carrier and Highway Safety.

There are eight major research and technology focus areas: regulatory evaluation and reform; compliance and enforcement; commercial driver performance enhancement; driver alertness and fatigue; driver physical qualifications; car-truck proximity; HAZMAT safety and cargo tank integrity; and crash causation and profiling.

Driver alertness and fatigue primarily supports current and future hours-of-service rule-making activities, along with fatigue outreach and fatigue management technology development.



Office of Motor Carrier Research and Standards

400 Seventh Street, SW
HMCS-30; Room 3107
Washington, DC 20590

Eye-Activity Measures of Fatigue and Napping as a Fatigue Countermeasure

Introduction

Commercial motor vehicle (CMV) driver inattention, particularly that due to fatigue, is widely recognized as an important safety issue in the transportation industry. The Federal Highway Administration's (FHWA) Office of Motor Carrier and Highway Safety (OMCHS) presently has more than 25 ongoing, planned, or recently completed research and technology projects relating to drowsiness/fatigue in CMV drivers. The goal of these efforts is to identify educational, operational, and technological countermeasures to combat driver fatigue, including the development of a vehicle-based capability to continuously monitor driver fatigue.

This tech brief summarizes an OMCHS study to investigate the potential of an eye tracking system for detecting reduced driver alertness, and to determine the impact of preventative napping on driver alertness and performance. The complete final report will be available from the National Technical Information Service.

Purpose

The study had three specific objectives:

Ocular Dynamics as a Predictor of Reduced Alertness

1. Prove the concept of utilizing specific measures of ocular dynamics, singly and in combination, as a reliable method for predicting decrements in driver alertness and performance.
2. Assess the relative importance and effectiveness of ocular parameters in four measurement categories and to do preliminary development of a predictive algorithm.

Preventative Napping as a Fatigue Countermeasure

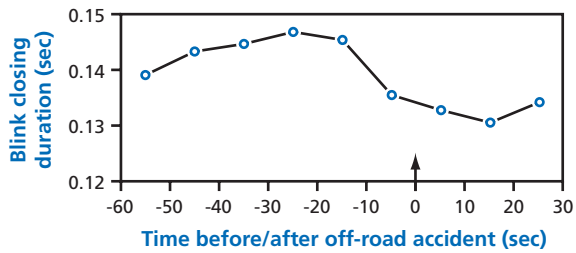
3. Assess the influence of an afternoon nap on driver alertness and performance following a night of abbreviated sleep.

Methodology

The data for this study were collected between September 1997 and February 1998. Nine professional drivers, eight males and one female, were recruited from the metropolitan Boston area. Eight truck drivers and one bus driver were selected; their long-haul driving experience ranged from 2 years to 24 years.

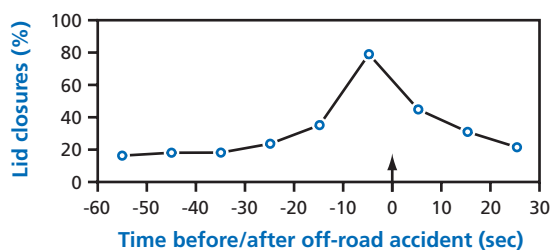
This driving simulator-based study had two conditions (Nap and No-Nap, in counter-balanced order), each lasting about two days. In both conditions, the first day served to familiarize the drivers with the testing facilities, and to give them extensive training,

Figure 1.
Mean blink closing duration.



Mean blink closing duration for seven participants. (Due to loss of data, results for two drivers could not be evaluated.) Closing duration began to decrease in the 10-second time period immediately preceding an accident and was the shortest in the 30 seconds following the accident.

Figure 2.
Eyelid closure occurrences.



Eyelid closure occurrences of the same seven participants per 10-second period, converted to a percentage. (Eight accidents were selected per subject; the maximum number of eyelid closures was 56.) It was readily apparent that the 10-second period immediately preceding the accident had the largest number of lid closures. The frequency of lid closures began to increase 20–30 seconds before the accident and showed a gradual decrease during the 30 second period following the accident. The duration of eyelid closures lasted from 0.5 seconds to 22 seconds.

including two 2-hour practice driving runs on the driving simulator.

The participants then slept in the laboratory, but time in bed was restricted to 5 hours. The second day included a 2-hour baseline driving run starting at 10:00 a.m. At the end of the driving run, the drivers completed the following tests: two Visual Analog Scales (VAS) for assessing subjective sleepiness and fatigue; resting electroencephalogram (EEG) recordings; and three computerized performance tests. The performance tests included a visual search and recognition task; a time estimation task; and a visual-motor coordination task.

Drivers in the Nap condition took a 3-hour nap in the afternoon, while drivers in the No-Nap condition spent that time engaged in various sedentary activities. The schedule then called for VAS, EEG, and performance testing, before drivers began a series of four 2-hour driving runs beginning at 10:00 p.m. Each driving run was followed by additional testing. Polysomnographic recordings were obtained during all scheduled sleep episodes.

Truck Driving Simulator

A fixed-base simulator was used to replicate the essentials of driving in a medium-sized heavy truck. During each driving run, participants encountered a sequence of interactive driving events, including straight and curved road segments; signalized and non-signalized intersections; workzones; oncoming vehicles, some of which encroached in the drivers' lane; and crosswinds. Drivers were also required to detect "pedestrians" appearing along the roadway and respond to specially designed target images presented in the rear view mirrors.

A monetary reward/penalty system was used to encourage participant motivation and good driving performance. Drivers were rewarded for finishing a run in less than a specified time, and were penalized for incidents like collisions, off-road accidents, and speeding tickets. Participants received a bonus for good performance, but were not actually required to pay a negative balance.

Eye Tracker

The eye tracker system used in this study acquired eye measurement data on all test participants, including blink duration and partial eye closures. The analyses performed on the data collected by the eye tracker sought to:

- Identify a number of blink and eyelid closure parameters;

- Follow the progression of these parameters across time-of-day (TOD) and time-on-task (TOT); and
- Examine possible associations of blinks and eyelid closures with off-road accidents.

Findings

Ocular Dynamics as a Predictor of Reduced Alertness

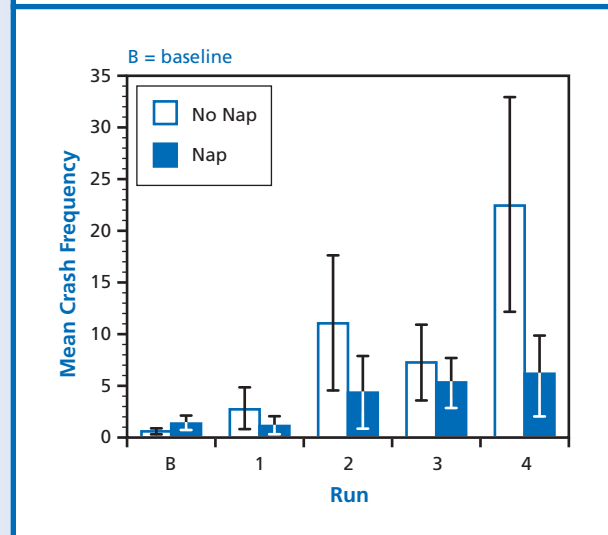
Ocular parameters were considered potentially useful for detecting drowsiness if they showed systematic changes across successive driving runs or across successive segments within a driving run, or if they showed consistent changes associated with impaired driver performance (unprovoked off-road accidents).

The study identified six parameters as potential candidates for detecting drowsiness.

- Blink duration measures derived from eye tracker and electrooculogram (EOG) data showed evidence of TOD and TOT effects. Blink closing duration was longer in the minute preceding off-road accidents than immediately after, and considerably longer than just before or at the start of the early driving runs (**Figure 1**).
- Blink frequency, as derived from EOG data showed TOD and TOT effects that were similar to those of blink duration. However, the results with blink frequency were less consistent than with blink duration.
- Partial eye closures during fixations, measured as the ratio of vertical to horizontal pupil diameter (V/H), showed clear TOD and TOT effects. The results show this parameter is particularly impressive as an indicator of degraded alertness at least 2 to 3 minutes before an accident and likely as much as 10 to 12 minutes before an accident.
- Eye closures occurred with a relatively high frequency in the minute preceding off-road accidents and showed a dramatic increase starting 20 to 30 seconds before the accidents (**Figure 2**).
- Saccade frequency (rapid eye movements), measured from EOG data, was markedly higher in the 30 seconds following as compared to the 60 seconds preceding off-road accidents.
- Large head and body movements, although not specifically measured in this study, were observed as being obvious indicators of fatigue.

Based on these results, a preliminary algorithm was

Figure 3.
Mean crash frequency across driving runs.



proposed that uses V/H as a measure of eye occlusion. Initial efforts to apply the algorithm to short data segments in the study showed promising results. Drowsiness scores early in the run, presumably while the driver is alert, were generally low. Scores were higher later in the run, possibly due to TOD effect, and were in larger peaks leading up to an unprovoked off-road accident. Time limitations of the study did not allow for extensive application of the algorithm to larger data segments.

Preventative Napping as a Fatigue Countermeasure

Another major objective of this study was to evaluate the effects of a scheduled 3-hour afternoon nap on nighttime driving behavior and on several other measures of alertness and performance in long-haul drivers.

The afternoon nap had a number of beneficial effects on driver alertness and performance. Subjective sleepiness and fatigue scores were significantly lower in the Nap than in the No-Nap condition in most of the night sessions. **Figure 3** presents the mean crash frequency of drivers in the Nap and No-Nap conditions in each of the four nighttime driving runs. Performance on the computerized tests was generally faster, more accurate, and less variable in the Nap condition. Beneficial effects of the afternoon nap on driving performance included significantly fewer crashes, shorter run completion times, and smaller standard deviations of lane position.

The study protocol proved to be more demanding than originally anticipated. Although the participants were professional truck or bus drivers and had considerable all-night driving experience, they reportedly

Researcher

This study was performed by the Trucking Research Institute, Alexandria, VA, Applied Science Group, Inc., Bedford, MA, the Institute of Circadian Physiology, White Plains, NY, and the Liberty Mutual Research Center, Hopkinton, MA, in collaboration with Professor John Stern of Washington University, St. Louis, MO. Contract No. DTFH61-96-00022.

Distribution

This Tech Brief is being distributed according to a standard distribution. Direct distribution is being made to the Resource Centers and Divisions.

Availability

The study final report will be available from the National Technical Information Service, Telephone: (703) 605-6000.

Key Words

eye tracking, ocular dynamics, fatigue, alertness, simulator, napping.

Notice

This Tech Brief is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The Tech Brief provides a synopsis of the study's final publication. The Tech Brief does not establish policies or regulations, nor does it imply FHWA endorsement of the conclusions or recommendations. The U.S. Government assumes no liability for its contents or their use.



U.S. Department of Transportation
Federal Highway Administration

April 1999

Publication No. FHWA-MCRT-99-010

found it difficult to complete the four scheduled night driving sessions after spending only 5 hours in bed. Several drivers were unable to start or finish the third scheduled driving run and were permitted to take an unscheduled nap instead, both in the Nap and No-Nap conditions.

Interestingly, the unscheduled naps, which lasted for 1 to 2 hours, had few beneficial effects. For example, subjective sleepiness and fatigue levels remained almost as high as they were at the end of the second night driving run. More importantly, driving performance was worse during the fourth driving run, after the unscheduled nap, than it was during the second, as indicated by larger penalties and more crashes.

These results suggest that preventative naps may be more beneficial than recuperative naps during all-night driving situations. Other studies have shown that naps taken early within a long period of sustained wakefulness have more beneficial effects than naps taken at later times. Researchers suggested that this be tested experimentally in future studies of scheduled napping as a fatigue countermeasure in long-haul driving operations.