Evaluation of Training Interventions to Mitigate Effects of Fatigue and Sleepiness on Driving Performance

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ABSTRACT

Fatigue and sleepiness are leading contributors to road crashes. Either can occur in the evening, sometime around 10:00 PM, after a day which begins in the morning, sometime around 8:00 AM. Other factors contribute as well to performance decrements in the evening for those who regularly work during the day. It is arguably the case that these various factors are responsible for the observed decrements in safety-critical driving skills such as hazard anticipation, hazard mitigation and attention maintenance which occur in the evening. However, it is by no means clear whether a training program can be designed which mitigates the effects that such factors have on these critical driving skills. A simulator experiment was undertaken to determine whether a training program (SAFE-T) could lead to improvements in the hazard anticipation, hazard mitigation and attention maintenance skills of drivers who had been awake for twelve hours. The results showed that on all three skills trained drivers performed significantly better during the post-test (after SAFE-T training) than the pre-test (before SAFE-T training) whereas the placebo drivers performed significantly worse during the post-test than the pre-test. Fatigue and sleepiness both increased during the post-test from their pre-test values. Thus, the effects of training are still observed even in the presence of increases in fatigue and sleepiness.
1 INTRODUCTION

Fatigue and sleepiness are often cited as factors contributing to road crashes. Worldwide, the percentage of road crashes attributed to fatigue and sleepiness varies greatly, depending on: how the crashes are examined, the population studied, the definition of the terms, and the details available on the crashes [1, 2]. This percentage has been estimated at upwards of 20% in the United States [3].

The level of sleepiness normally increase towards the end of the waking day of at least twelve hours, attributed in no small measure to the changes in the endogenous circadian rhythm and the homeostatic need for sleep [4], except in the rare cases where these are desynchronized. The increase in these levels typically leads to reductions in alertness and performance. For example, a clear decrease is seen in measures of performance as simple as response time [5] and as complex as logical reasoning, working memory and other executive functions [6] after an extended period (eight or more hours) of wakefulness. The effect of sleepiness on performance are often most apparent when the demands on the individual are relatively few [7].

The effects of fatigue often also increase over the course of the day. Individuals who are fatigued are not necessarily sleepy. Many individuals have jobs which are physically demanding. But a number of other job factors lead to increases in fatigue [35]. It has been estimated that fatigue is present in close to 20% of the workers in a sample of 12,095 workers from 45 companies [35]. Increases in fatigue are themselves associated with decreases in cognitive performance [36].

Changes in skill performance over a twelve hour period are especially important in professions like nursing. In the nursing profession, long shifts are often the norm and referred to as extended hour shifts (defined as shifts longer than 8 hours per day – [8], e.g., a 12-hour shift). Many studies have shown that extended hour shifts have a significant impact on: nurses’ performance during working hours that compromise patient safety, e.g., increasing patient care errors [9, 10]; and nurses’ health and well-being, both during the working hours, e.g., leading to needle-stick injuries [11], and in the long run, e.g., leading to musculoskeletal problems [12].

Perhaps not surprisingly, nurses are at an increased risk of crashing when assigned to an extended hour shift. Specifically, compared to shorter shifts of less than 8.5 hours, the risk for drowsy driving episodes among nurses is doubled (odds ratio 2.00; p < .01) and the risk for crashes or near-crashes is almost doubled (odds ratio 1.84; p = .03) when nurses worked more than 12.5 hours [13].

Until recently, it was not known which one or more of the various driving skills are influenced by fatigue and sleepiness and their corresponding effects on alertness and performance. The three critical driving skills that have been linked in the literature to crashes are hazard anticipation [14], hazard mitigation [15] and attention maintenance [16]. Hazard anticipation is defined as the ability to predict threats which are latent or actual [17]. Hazard mitigation is defined as the ability to take appropriate precautionary measures once a threat has been identified, including initiating appropriate eye, hand and foot behaviors [18]. And attention maintenance is defined most often as the ability to limit the number and duration of glances inside the vehicle when performing a secondary task which requires such glances [19].

Recent studies have shown that all three skills are compromised in drivers twelve hours after their normal waking time. For example, the percentage of latent hazards anticipated decreased from 67% soon after waking to 42% twelve hours later [20]. Related to this, response times are slower to actual threats among sleepy drivers than among non-sleepy drivers [21]. Attention maintenance is also compromised and, in particular, the percentage of especially long glances inside the vehicle increased from 69% to 93% twelve hours after waking [20]. And, finally, hazard
mitigation is compromised. For example, the acceleration from a stop bar when taking a left turn at an intersection increased from 1.62 ft. $s^2$ soon after waking to 2.11 ft. $s^2$ 12 hours later [20]. Rapid accelerations (and quick stops) are associated with clear increases in crash risk [21].

Interestingly, hazard anticipation, hazard mitigation and attention maintenance are the same three skills that are compromised in novice drivers [14, 23, 24, 25]. This raises the question of whether those programs that have successfully been used to train novice drivers’ hazard anticipation [e.g., 26], hazard mitigation [e.g., 27] and attention maintenance [e.g., 28] skills would also work for drivers who were fatigued and/or sleepy.

There is little reason to expect the training programs to work as effectively with fatigued and sleepy drivers, if only because the effects of fatigue and sleepiness are so devastating. For example, the 100 Car Naturalistic Driving Study shows that driving while fatigued increased the risk of a crash or near-crash by nearly four to six times [16]. Furthermore, a case-control study by Cummings and colleagues also shows the same pattern in which the crash risk was fourteen times higher for drivers who were reported to have almost fallen asleep while driving [28]. Perhaps it is not at all surprising that fatigue and sleepiness should have such large effects given that together they impact levels of alertness and performance [6] that are critical to maintaining hazard anticipation, hazard mitigation and attention maintenance skills at high levels. Thus, at best it is expected that trained drivers at the end of the day might perform no worse than they did before training at the beginning of the day.

2 METHOD

The purpose of the study is to determine if a sleepiness and fatigue evaluation – training program (SAFE-T) [36] which was administered in the morning to student nurses with relatively high levels of fatigue and sleepiness allows them to perform better at the end of the day on each of the three critical driving skills described above than student nurses with similar levels of fatigue and sleepiness who were not exposed to the training program.

2.1 Training Program

The SAFE-T training program consists of 4 modules, all presented in PowerPoint: hazard anticipation training, hazard mitigation training, attention maintenance training, and review of the training program lasting approximately 45 minutes in total duration. Brief descriptions of the training modules are given below. The three elements that have been shown to be critical to the success of a PC-based driver training program were employed here. These elements include allowing drivers to make mistakes, explaining to drivers how to modify their behaviors so that they understand their mistakes, and letting drivers then master the scenario in which a mistake was made. The training modules begin with the definition of the skill followed with written descriptions of scenarios and perspective views.

2.1.1 Hazard Anticipation Module

For each of four scenarios (all scenarios with latent hazards) presented in the hazard anticipation module, the trainee is provided with a written description of the scenario and the top down view of the scenario. Then, the trainee is shown a perspective view of the scenario and asked to click on a location from behind which the hidden hazard could potentially appear in the scenario, being given a total of three chances to click on the correct location. The trainee is given an explanation of what is the correct answer and why, that feedback made contingent on the trainee’s response (correct or incorrect). Lastly, the trainee is given a review of the scenario.
2.1.2 Hazard Mitigation Module
Training of hazard mitigation begins with hazard anticipation training since hazard mitigation depends on prior anticipation and recognition of a potential or actual hazard. Thus, as a first step, the trainee is asked to click on an object that seems to be the risky hazard in the scenario, and is given three chances to click on the correct hazard. The trainee is given an explanation of what is the correct answer and why. The trainee is then asked to indicate how he or she would mitigate the potential hazard, either by steering to the left or right or changing the speed. Again the trainee is given three chances to get the answer correct and is given an explanation of what is the correct answer and why. Note that all hazards were visible in the hazard mitigation module.

2.1.3 Attention Maintenance Module
The training involved the participant viewing either a display of a map or a video of the forward roadway, but not both. The training began with the video of the roadway. The participant used one of two buttons to alternate between the view of the roadway ahead and the view of a map: clicking on the ‘MAP’ button displayed a map on the screen and clicking on the ‘DRIVE’ button brought back the view of the driving video. The trainee was given 20 seconds to find on a map the name of any street that intersects the street on which he or she was travelling in the scenario. If the trainee glanced at the map for more than two seconds, he or she would hear a ‘beep’. For each scenario, the trainee was given two trials to successfully complete the map task (i.e., completing the map task successfully required that all of the trainee’s glances were not more than two seconds). If all the glances were less than two seconds, the trainee was asked to enter the name of the intersecting street of the given street name. The trainees’ overall training score was penalized for each misidentified street name.

2.1.4 Review
The training program modules were then followed by the review of each driving skill – hazard anticipation, hazard mitigation, and attention maintenance – given to the trainee.

2.2 Participants
Thirty-six licensed students, aged 18 – 45 (average age = 20.25 years, SD = 1.44), from the College of Nursing (at the University of Massachusetts Amherst) with an average driving experience of 3.5 years (SD = 1.59) were recruited for the study. The participants were required to normally be a morning person, i.e., generally sleep about 6-8 hours a night and generally wake up between 6:00 a.m. - 9:00 a.m.

2.3 Apparatus
2.3.1 Driving Simulator
The System Technology Inc. three-channel driving simulator system – STISIM system – consisting of a built-up cab with three 60” screens was used for the experiment.

2.3.2 Eye Tracker
The eye tracking system that was used in the experiment is an ASL Mobile Eye from Applied Science Laboratories equipped which was accurate to within 0.5 degrees of visual angle.
2.4 Experimental Design

In the study, all participants completed two driving simulator evaluations of their hazard anticipation skills, hazard mitigation skills and attention maintenance skills: a pre-test evaluation in the morning before training and a post-test evaluation in the evening after training (experimental or control). Across both evaluations, participants navigated two of four possible drive sets. Each drive set consisted of four different virtual environments (residential, rural, town and highway). Each virtual environment contained three scenarios, one evaluating hazard anticipation, one evaluating hazard mitigation and one evaluating attention maintenance (see below). The order of the four virtual environments and twelve scenarios used to test a given skill was counterbalanced across virtual environments and the virtual environments were counterbalanced across drive sets.

2.4.1 Evaluation Scenarios

The four hazard anticipation scenarios are described in Table 1 below.

Table 1: Descriptions for Hazard Anticipation & Hazard Mitigation Scenarios in each of Four Virtual Environments: Town, Rural, Residential and Highway

<table>
<thead>
<tr>
<th>Hazard Anticipation Scenario (Virtual Traffic Environment)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck Crosswalk (Town)</td>
<td>The participant approaches a midblock crosswalk and should look for hidden hazards (e.g., pedestrians) that might be obscured by a truck stopped next to the right curb in the travel lane before the mid-block crosswalk.</td>
</tr>
<tr>
<td>Adjacent Truck Intersection (Rural)</td>
<td>The participant is driving straight in the right travel lane on an arterial road (four travel lanes, two in each direction) with side streets on the right and left and should look for hidden hazards across the intersection in the opposing lane that might be obscured by a line of turning left trucks in the adjacent left travel lane.</td>
</tr>
<tr>
<td>Obscured Intersection (Residential)</td>
<td>The participant approaches a stop sign-controlled intersection with a marked crosswalk. After coming to a full stop the driver should look for a hidden hazard that might be obscured by hedges on the right hand side of the road before pulling out into the intersection.</td>
</tr>
<tr>
<td>Multiple-Lane Intersection (Highway)</td>
<td>While crossing a traffic signal-controlled intersection, the participant should look for potential hidden hazards (e.g., cross traffic) that might be obscured by a bus, which is approaching from the right. The bus is traveling in the left lane of the two travel lanes that are available to cross traffic coming from the left. The signal turns green at the last minute for the participant.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard Mitigation Scenario (Virtual Traffic Environment)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Parking Lane (Highway)</td>
<td>The driver is traveling on the right side of a two lane roadway. There is a car that pulls out from a parking lane on the right and serves as a cue to notify the driver that he or she is approaching an area with parked cars that might pull out. When the driver approaches the parking lane, one of the cars in the parking lane (hazard instigator) activates its left signal light (blinking). The scenario is used to determine whether the driver takes actions in order to avoid a possible conflict with that car. In addition, the scenario is also used to determine if the driver looks at the hazard instigator and its left turn signal.</td>
</tr>
<tr>
<td>Bus Bicyclist (Town)</td>
<td>A bus is stopped at the bus stop ahead of the driver (picking up passengers) and there is a bicyclist riding in front of the driver who approaches the bus from...</td>
</tr>
</tbody>
</table>
behind. The scenario is used to determine whether the driver takes actions to avoid hitting the bicyclist in case the bicyclist veers to the left (in order to pass the bus) and into the driver’s travel lane as it approaches the stopped bus. However, the bicyclist never veers into the driver’s lane and instead turns onto the sidewalk.

**Opposing Lane Road Work (Rural)**

There is a work zone ahead traffic sign that serves as a cue to the driver that there is a work zone further ahead. Then, the driver has to drive through a marked worked zone (including cones and a construction vehicle) that blocks traffic in the opposing lane. In addition there is an approaching vehicle (hazard vehicle) in the opposing lane downstream of the work zone. When the driver is approaching the work zone area, the vehicle in the opposing lane steers slightly towards the median of the roadway indicating it may attempt to pass around the road work before the driver does. The scenario is used to determine whether the driver mitigates potential collisions with the vehicle in the opposing lane.

**Turn Left Pedestrian (Residential)**

This scenario takes place at a stop sign-controlled intersection with crosswalks. The driver turns left at the intersection. Two pedestrians are standing still at the corner diagonally to the left of the driver and engaged in a conversation. Once the driver passes the stop line, the two pedestrians begin to move. The scenario is used to determine how the driver mitigates potential collisions with the pedestrians at the intersection assuming the pedestrian might attempt to enter the crosswalk. The pedestrian waits at the intersection for the driver to pass over the crosswalk.

Note that the first three hazard mitigation scenarios involve situations where the driver does not necessarily need to slow down (unless he or she identifies the threat) while the last scenario (Turn Left Pedestrian) includes a stop sign-controlled intersection where the driver must stop or significantly slow down before proceeding. The former three scenarios are labeled *non-slowing* scenarios, while the latter scenario is labeled a *slowing* scenario.

The attention maintenance scenarios consisted of straight two-lane roads with no lead vehicle events, no ambient traffic, or any sort of hazard materialization. All attention maintenance tasks chosen were in-vehicle tasks that required the driver to glance away from the forward roadway in order to complete the tasks. They included: getting the proper change for a toll, determining whether streets were present on a map, dialing a telephone number, and finding a CD in a CD case. The task was initiated at a fixed location on the roadway in each scenario and was similar for each participant. Participants were given 20 seconds to complete each task. Participants who finished the task within the 20 seconds had to say “done”; otherwise at the end of the 20 seconds period they heard a ‘beep’ tone indicating that they should stop engaging with the secondary task and return to the driving task.

### 2.4.2 Procedure

There were four phases in the experiment. These include the pre-experimental, pre-training evaluation, training, and the post-training evaluation phase. The pre-experimental phase was an online session while the latter three phases took place at the laboratory where both the evaluation phases occurred on the driving simulator while the training phase was delivered on a PC. Each evaluation drive took roughly 15 minutes to complete.

#### 2.4.2.1 Pre-Experiment

All participants completed an online consent form indicating agreement to answer the online survey and participate in the study. The survey included demographic questions and a general
health questionnaire that was adopted from Morningness-Eveningness Questionnaire [30], Pittsburgh Sleep Quality Index [31], and Epworth Sleepiness Scale [32]. Based on this final score on the survey, a participant was pseudo-randomly assigned to either the training (SAFE-T) or placebo group such that the distribution of final scores of the participants in the two groups were roughly the same. Participants were asked to opt for their busiest day of the week in order to ensure that they remained awake and occupied between the two evaluation sessions.

2.4.2.2 Pre-Training Evaluation Phase: Driving Simulator

The pre-test evaluation session started either at 9:00 a.m. or 10:30 a.m. This was done so that we could run at least two participants each day. Participants were asked to complete fatigue and sleepiness subjective rating scales that were adopted from the Samn-Perelli Fatigue Scale [33] and Stanford Sleepiness Scale [34]. Participants were then given a practice drive to get acclimated to the controls of the simulator following which they were fitted with eye tracking glasses and calibrated. Subsequently, participants completed a pre-test evaluation (consisting of the above four environments) on the driving simulator. Each virtual environment took between three and four minutes to navigate in the simulator. There was a brief break between each virtual environment in a drive.

2.4.2.3 Training Phase: SAFE-T and Placebo

The training session followed immediately after the pre-test simulator evaluation session which was approximately at 9:45 a.m. or 11:15 a.m. Upon completion of the training, participants filled out a payment voucher and were paid $20 for completing the pre-test evaluation and training session. Participants were also reminded to refrain from taking any naps between the two sessions, and were asked not to consume any form of caffeine in the four hours prior to the second evaluation.

SAFE-T training was administered to the participants assigned to the experimental group. Participants were briefed about the program and were told that it consists of four sections. Participants were required to complete all four sections estimated to last about 45 minutes on average. Participants’ performance during the training session was monitored by the experimenter from a secondary display (experimenter workstation) linked to the training PC.

The placebo training was given to participants assigned to the control group. The placebo training involved a video discussion of relatively elementary driver skills, e.g., changing tires and information on motor oil, none of which related to hazard anticipation, hazard mitigation or attention maintenance.

2.4.2.4 Post-training Evaluation: Driving Simulator

At the post-training simulator evaluation session, participants were calibrated with eye-tracking glasses, and completed a post-test evaluation, similar in all respects to the pre-training evaluation [33, 34]. After completing the evaluation session (either at 9:00 P.M. or 10:30 PM, depending on when the participants were trained), participants filled out a payment voucher and were paid $30 for their time.

2.5 Dependent Variables and Hypotheses

The dependent variables and hypotheses are listed in Table 2. There are separate variables (and hypotheses) for each of the three driving skills.
### Table 2: List of Dependent Variables & Hypotheses

<table>
<thead>
<tr>
<th>Driving Skill</th>
<th>Dependent Variable</th>
<th>Hypotheses</th>
</tr>
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<tbody>
<tr>
<td><strong>Hazard Anticipation</strong></td>
<td>Hazard identification (1-hit, 0-miss). Drivers received a score of 1 if they glanced towards the target zone (the area in which the potential hazard is hidden, e.g., to the left edge of the truck closer to its front in the Truck Crosswalk Scenario) while in the launch zone (the area where it is crucial for a participant to anticipate the hazard, e.g., from the emergency cone behind the truck until the beginning of the crosswalk for the Truck Crosswalk Scenario).</td>
<td>The placebo group is expected to have fewer glances towards the target zone during the post-test than during the pretest.</td>
</tr>
<tr>
<td><strong>Hazard Mitigation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Non slowing Scenarios</td>
<td>Hazard identification (1-hit, 0-miss).</td>
<td>The same predictions hold here as for hazard anticipation above.</td>
</tr>
<tr>
<td></td>
<td>Lateral distance from the hazard (feet). The lateral lane position of the vehicle will be measured.</td>
<td>The drivers in the placebo group will drive closer to the potential hazard during the post-test than during the pretest. Additionally, there will be an interaction between time of testing and type of training.</td>
</tr>
<tr>
<td></td>
<td>Velocity (miles per hour). The velocity of the vehicle will be measured.</td>
<td>When approaching the hidden hazards, drivers in the placebo group will drive faster during the post-test than during the pre-test. Additionally, there will be an interaction between time of testing and type of training.</td>
</tr>
<tr>
<td>b) Slowing Scenario</td>
<td>Hazard identification (1-hit, 0-miss). Drivers received a score of 1 if they glanced at a pedestrian, who is attempting to cross the crosswalk, before entering the intersection</td>
<td>The untrained and trained group are expected to detect the same percentage of hazards in the pre-test and post-test.</td>
</tr>
<tr>
<td></td>
<td>Acceleration (feet/s^2). The acceleration of the vehicle will be measured.</td>
<td>When approaching the visible hazards, drivers in both groups will accelerate equally fast during the post-test and pre-test.</td>
</tr>
<tr>
<td><strong>Attention Maintenance</strong></td>
<td>In-Vehicle Glance Durations (seconds). Glance durations inside the vehicle while performing the secondary tasks were measured. The total number of glances and the number of glances that were greater than 2 seconds were recorded.</td>
<td>For the placebo group, the percentage of glances greater than 2 seconds will be larger during the post-test than during the pre-test. There will be an interaction between the type of training and the time of testing.</td>
</tr>
</tbody>
</table>

### RESULTS

3.1 Changes in Sleepiness and Fatigue

Changes were observed in the sleepiness and fatigue of both the placebo and trained group. The average scores for placebo group were: (i) Samn-Perelli Fatigue: 2.70 after pre-test and 3.25 after the post-test; (ii) Stanford Sleepiness Scale: 2.30 after pre-test, and 3.10 after post-test. The average scores for trained group were: (i) Samn-Perelli Fatigue: 3.21 after pre-test and 3.84 after the post-test; (ii) Stanford Sleepiness Scale: 2.74 after pre-test and 3.53 after post-test.
3.2 Hazard Anticipation

For each scenario, a launch zone and target zone were defined. A participant was given a score of either 0 or 1: 1 if a participant glanced while in the launch zone at the target zone; 0 if the participant did not glance at the target zone while in the launch zone. In each of the four environments, the performance of the trained group was better on the post-test than on the pre-test whereas the reverse was true for the placebo group. The difference in the placebo and trained groups on the post-test is over 33 percentage points. Put differently, the trained group anticipated almost three times as many hazards on the post-test as did the placebo group.

To examine statistical effects, a logistic regression model within the framework of Generalized Estimating Equations (GEE) was used. The model included the participants as a random effect and the following three factors as fixed effects: (1) Group: Trained and Untrained - between subjects; (2) Scenario (or Environment) – within subjects; and (3) Pre-Post: Pre-test and Post-test – within subjects. All second and third order interactions were also included. Using a backwards elimination procedure the final model included two significant main effects of Group [Wald $X^2=8.44$; $p=0.004$] and Scenario [Wald $X^2=16.019$; $p=0.002$]. In addition there was one significant second order interaction of Group and Pre-Post [Wald $X^2=10.511$; $p=0.001$]. Since our focus is on whether or not training was efficient we focus on the interaction between Group and Pre-Post are presented in Figure 1.

3.3 Hazard Mitigation

In order to know whether hazard mitigation is impaired it is necessary to determine whether the hazard has been anticipated in the first place.

3.3.1 Percentage of Hazards Anticipated

On average, the trained group anticipated 97.22% of the hazards on the post-test whereas they anticipated only slightly fewer (88.89%) of the hazards on the pre-test. By comparison, the placebo group anticipated only 79.17% of the hazards on the post-test, but fully 87.50% of the hazards on the pre-test. There are two scenarios -- Bus Bicyclist (T) and Opposing Lane Road Work (L) -- in
which 100% of the hazards were anticipated by both groups (placebo and trained) during both the pre-test and post-test. In the other two scenarios -- Car Parking Lane (H) and Turn Left Pedestrian (R) -- the performance of the trained group during the post-test is always better than their performance during the pre-test. The reverse is true for the placebo group.

In order to determine the effects of training on hazard anticipation, a logistic regression model within the framework of Generalized Estimating Equations (GEE) was used. The Logistic Regression Model is unable to handle probability values of exactly 1.0. Convergence issues are created within the model leading to unreliable results. Therefore, two of the scenarios -- Bus Bicyclist and Opposing Lane Road Work -- were taken out from the analysis. The model included the participants as a random effect and the following three factors as fixed effects: (1) Group: Trained and Untrained; (2) Scenario: Car Parking Lane and Turn Left Pedestrian; and (3) Pre-Post: Pre-test and Post-test. All second and third order interactions were also included. Using a backwards elimination procedure the final model revealed two significant main effects of Group [Wald $X^2=7.553; p=0.006$] and Scenario [Wald $X^2=16.503; p<0.01$]. In addition, there was one significant second order interaction of Group and Pre-Post [Wald $X^2=5.181; p=0.023$]. The summary of the interaction is presented in Figure 2.

![Figure 2. Summary of the interaction between group of drivers and pre-post test](image)

### 3.3.2 Non-Slowing Scenarios

For the rest of the hazard mitigation analyses, the scenarios were classified into the two types as defined earlier (i) three non-slowing scenarios and (ii) one slowing scenario.

#### 3.3.2.1 Lateral Position

In order to investigate whether drivers maintained their lateral position, the average lateral position was computed at each one second interval for the last 10 seconds before a hazard. The lateral position was set equal to the distance from the right hand side of the road. If this difference is positive, the drivers are further to the right in the post-training drive. The results show that the drivers in the trained group drove further away from the potential hazard (in terms of lateral position) as they approached the hazard zone during the post-test than during the pre-test (the difference increased in size). In contrast, the drivers in the placebo group always drove closer to
the potential hazard (in terms of lateral position) as they approached the hazard zone during the post-test than during the pre-test (the difference decreased in size).

The difference was regressed on time. The slopes for each group of drivers in each environment were estimated as well as the intercepts. The slopes for trained drivers in all environments were positive (rural, 0.118; town, 0.058; highway, 0.037) whereas those for the untrained drivers were negative (rural, -0.092; town, -0.080; highway, -0.014). The slopes of trained and placebo groups differed in the rural (z = -3.53, p=.0004) and town (z = -2.137, p=0.0201) environments, but not in the highway environments.

3.3.2.2 Velocity

In order to investigate whether drivers maintained their speed, the average velocity was computed at each one second interval for the last 10 seconds before hazards. The results show that the trained group drove slower during the post-test than did the placebo group in all three scenarios. Across time, the difference between the velocities of the post- and pre-training drive of the placebo participants was significantly larger than the difference between the velocities of the post- and pre-training drive of the trained participants.

The difference was regressed on time. The slopes and intercepts for each group of drivers in each environment were estimated. The slopes for the trained and placebo drivers in all environments did not differ from one another, indicating time (approaching the hazard) did not affect the difference between the post-test and pre-test velocities. The intercepts for the trained and placebo drivers in the rural environment differed significantly from one another (z = 6.82, p = 0.000) and were marginally different from one another in the highway environment (z = 1.52, p = 0.127), indicating that the difference in the post-test and pre-test velocities of the placebo drivers in the rural (highway) environment was positive and much larger than this difference in the velocities of the trained environments in this environments (a difference which was negative).

3.3.3 Slowing Scenario

3.3.3.1 Percentage of Secondary Glances toward the Hazard

In the Left Turn Pedestrian scenario, the secondary glance -- monitoring the potential hazard, a pedestrian -- is crucial before a driver enters the intersection and then turns left at the intersection. In order to analyze how hazard anticipation skills varied across the different conditions in the experiment, a logistic regression model within the framework of Generalized Estimating Equations (GEE) was used. The model included the participants as a random effect along with two fixed factors: (1) Group: Trained and Placebo; and (2) Pre-Post: Pre-test and Post-test. A second order interaction was also included. Using a backwards elimination procedure the final model revealed one significant second order interaction of Group and Pre-Post [Wald X²=6.378; p=0.012].

In order to further analyze the interaction, a post hoc pairwise comparisons analysis using the Bonferroni correction was applied. The post hoc analysis indicated that the only significant difference was between the placebo post and the trained post (p=0.013). The trained group glanced significantly more often towards the pedestrian than the placebo group during the post-test.

3.3.3.2 Acceleration

In order to investigate whether drivers accelerated gradually after they stopped/slowed at the stopline (before they initiated a left turn at the intersection), their average acceleration was calculated from the stop-line before the intersection to the beginning of the crosswalk (the one at which the potential hazard could occur). Performance of the trained group during the post-test is better than
during the pre-test, whereas, the reverse is true for the placebo group. Specifically, the trained group accelerated more slowly during the post-test than the pre-test; conversely, the placebo group accelerated faster during the post-test than the pre-test. This suggests a training effect on hazard mitigation.

In order to analyze this variable, a Linear Mixed Model (LMM) was used. The model included the participants and the scenarios as random effects along with the following two fixed factors: (1) Group: Low Fatigue and High Fatigue; and (2) Pre-Post: pre-test and post-test. The second order interaction was also included. Using a backwards elimination procedure the final model included one significant second order interaction of Group and Pre-Post [F (1, 68) = 6.158; p=0.016]. In order to analyze the interaction, post hoc pair-wise comparison analysis using the Bonferroni correction was utilized. This analysis revealed that while there was no difference between the pre-test and post-test for the trained group (p=0.132), placebo drivers accelerated significantly more during the post-test than during the pre-test (p=0.05).

### 3.4 Attention Maintenance

#### 3.4.1 Glances inside the vehicle more than 2 seconds

In order to analyze whether drivers maintained their attention on the forward roadway, a decision was made to analyze the number of glances inside the vehicle that were longer than 2 seconds during the performance of the task. The two second criterion is based on other studies [19].

The performance of the trained group during the post-test was better than their performance on the pre-test. However, the reverse was found to be true for the placebo group. The trained group had fewer in-vehicle glances greater than 2 seconds during the post-test (1.50) than during the pre-test (1.79) while the placebo group had a larger number of in-vehicle glances greater than 2 seconds during the post-test (2.58) than during the pre-test (1.82). This indicates a training effect on attention maintenance.

In order to analyze this variable, a Poisson regression model with a random intercept within the framework of Generalized Estimating Equations (GEE) was used. The model included the participants as a random effect along with the following three fixed factors: (1) Group – Trained and Placebo; (2) Scenario Number -- Change, Map, Cell, and CD; and (3) Pre-Post -- Pre-test and Post-test. A natural logarithm (ln) of the total number of glances was included as a covariate in the model (included because of the Poisson distribution of this variable). The model also included all second and third order interactions. Using a backwards elimination procedure the final model included two significant main effects of Group [Wald $X^2=6.108; p=0.013$] and Scenario [Wald $X^2=10.833; p=0.013$]. In addition there was one significant second order interaction of Group and Pre-Post [Wald $X^2=8.951; p=0.003$].

In order to analyze the interaction, post hoc pair-wise comparison analysis using the Bonferroni correction was utilized. This analysis revealed that while there was no difference between Placebo and Trained groups during the pre-test, there was a significant difference between the groups during the post test. The Placebo group tended to have significantly more glances greater than 2 seconds during the post-test than the trained group (p<0.01). In addition, while there was no difference between the pre- and post-test for the Placebo group; however, drivers who were trained made significantly fewer especially long glances during the post-test than the pre-test (p=0.029).
Fatigue and sleepiness represent a major hazard on our roadways. Drivers leaving work after a long shift are apt to be especially fatigued and/or sleepy. Nurses have been shown to be at higher risk after long shifts of crashing than after short shifts [13]. But nursing is only one of many occupations where long shifts are often the norm. An intervention which could reduce the likelihood of crashes due to fatigue and sleepiness could be of real benefit.

One such intervention (SAFE-T) was evaluated above. The intervention targeted the three skills that are known to be the cause of most crashes: hazard anticipation [14], hazard mitigation [15] and attention maintenance [16]. The participants were both sleepier and more fatigued on the post-test than they were the pre-test. We wanted to know whether increases in sleepiness and/or fatigue would make the training program no longer effective.

With respect to hazard anticipation, drivers given SAFE-T training were more likely to anticipate hazards at the end of the day (after training) than they were at the beginning of the day (before training). On the contrary, drivers given placebo training were less likely to anticipate hazards at the end of the day than they were at the beginning of the day. Note that we cannot prove that drivers who glanced at the area where the hazard emerged actually were so glancing because they anticipated a hazard to emerge. But from the standpoint of safety this may not be entirely relevant. Drivers who do not glance cannot take an action to mitigate a potential hazard. Drivers who do glance can see the hazard even if they did not anticipate it, though they may respond more slowly if they were not anticipating it.

With respect to hazard mitigation, the drivers anticipated the hazards 100% of the time in two of the scenarios. In the other two hazard mitigation scenarios, the trained drivers were more likely to anticipate a hazard on the post-training drive than the pre-training drive. There was no difference in the performance of the placebo drivers. The hazard mitigation scenarios were further partitioned into those where slowing was not required and where slowing was required. In the non-slowing scenarios, drivers in the trained group moved further away from the potential threat and reduced speed more in the post-training drive than did drivers in the untrained group. In the slowing scenario, somewhat to our surprise, the trained group glanced more often towards the latent hazard and accelerated less quickly on the post-training drive than they did on the pre-training drive. There was no difference on either of these measures for the placebo group. This was something of a surprise because [7] had shown larger effects of fatigue and sleepiness in scenarios where extra attention was required (the slowing scenarios in our experiment). Conservatively, we had hypothesized that there would be no effect of training in the slowing scenario.

Finally, with respect to attention maintenance, it was found that the number of glances longer than the threshold duration decreased for the drivers in the trained group from the pre-training to the post-training evaluation drives, but that this number increased for the placebo group. The interaction was significant.

4.1 Limitations

There are several limitations in the study. First, participants in both groups were asked to not take a nap or sleep or consume caffeinated beverages between the pre-test and post-test. However, it was not possible to determine definitively if the restriction was followed because participants were allowed to leave after the pre-test and only came back to the laboratory prior to the post-test. Second, if a group of older, experienced drivers were randomly assigned to SAFE-T training and placebo training, one might see little or no improvement immediately after training (since both
were at ceiling) and a similar loss after being awake for a prolonged period of time. Third, it cannot be determined from this study whether it is sleepiness, fatigue, or some other factor correlated with the time between the morning and evening administration of the training evaluation drive that is causing the drop in performance on the post-test. What can be ascertained however is that at the end of a prolonged period of wakefulness for individuals who are generally morning people and who generally get eight hours of sleep a night, performance on the critical skills of trained drivers at the end of the day is better than that of untrained drivers. Moreover, this effect holds even when fatigue and sleepiness increase. Fourth, it is worth noting again that the study was done on a driving simulator, not on the open road. Fifth, the drivers in the trained and untrained groups may have chosen qualitatively different days as the days on which they were most busy. Finally, the effects of training were evaluated 12 hours after being administered. Retention effects of the training need to be investigated.

4.2 Summary
In theory, one hour of training goes a long way. A PC-based training program has been designed and evaluated which can significantly decrease the decrement in three critical driving skills as observed and measured on a driving simulator among a sample of student nurses. If SAFE-T were evaluated in the field and were shown to have long term benefits on the three critical driving skills, it should be relatively easy to implement in an applied setting, not only among nurses but among the broader population of drivers for whom long shifts are the norm (e.g. truck drivers, graveyard shift workers, emergency 24 hour on-call personnel etc.). It remains to be determined whether these effects will generalize to the open road and for how long those effects will persist.

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