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Final Report

The Effects of In-Lane Rumble Strips on the Stopping Behavior of Sleep-Deprived Drivers

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16. Abstract (Limit: 200 words)

This study is the second in a series investigating rumble strips. The objective was to determine the effect of rumble strips on the stopping performance of *sleep-deprived* drivers. [The study was nested in a larger fatigue study with components unrelated to rumble strips.] The participants were 20 commercial motor vehicle drivers. Each participant was tested over a twenty-hour period, driving in a driving simulator for one hour in the morning, afternoon, evening and at night. During each drive, the participants encountered two stop-controlled intersections—one *with* rumble strips and the other *without* rumble strips. The *braking pattern* of the drivers was affected by the presence of rumble strips— from the appearance of the first set of rumble strips [218 meters (715.2 ft) from the intersection] until the drivers stopped at the intersection. The mean speed of drivers approaching the intersection *with* the rumble strips was statistically significantly slower than the mean speed for drivers approaching the intersection *without* the rumble strips. Though sleep deprivation did not affect the driver's braking patterns on the approach to the intersections, it did affect steering variability throughout the course of the drive.

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The Effects of In-Lane Rumble Strips on the Stopping Behavior of Sleep-Deprived Drivers

Final Report

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EXECUTIVE SUMMARY

This is the second in a series of three studies conducted by the authors in order to investigate various aspects of rumble strips. According to the Manual on Uniform Traffic Devices (MUTCD, 2001) rumble strips are used to "alert drivers to unusual motor traffic vehicle conditions through noise and vibration" to attract their "attention to such features as changes in alignment and conditions requiring a stop" (MUTCD, 2001, page F-64). All three studies in the series focus on the latter usage.

The first study in the series, conducted by Harder, Bloomfield, and Chihak, 2001, used a driving simulator and involved participants who were *attentive* drivers. The study showed that rumble strips affected the *braking pattern* of drivers—they used the brakes to a greater extent *earlier* in the slowdown process than they did if there were no rumble strips. A subsequent field study (Fitzpatrick, Brewer, & Parham, 2002) found similar results.

In the study reported here, the second in the series, the objective was to investigate the effect of in-lane rumble strips on the stopping performance of *sleep-deprived* drivers. [It should be noted that the study was nested in a larger fatigue study and thus has components that are not directly related to an investigation of the effects of rumble strips.] The participants were 20 commercial motor vehicle drivers. Each participant was tested over a twenty-hour period, during which he or she was continuously awake. During the period the participants drove in a driving simulator for approximately one hour on four occasions throughout the day—in the morning, the afternoon, the evening and at night. Towards the end of the 59.53-mile test route, the participants encountered two stop-controlled intersections—the first *with* rumble strips and the second *without* rumble strips.

The key finding of the study was that, despite the fatigue of the drivers, the *braking pattern* of the drivers was affected by the presence of the rumble strips. From the appearance of the first set of rumble strips, 218 meters (715.2 ft) from the intersection up to the point at which the drivers stopped, the mean speed of drivers approaching the intersection *with* the rumble strips was statistically significantly slower than the mean speed for drivers approaching the intersection *without* the rumble strips. The drivers began to brake to a greater extent from the point at which the rumble strips occurred on the approach to the stop-controlled intersection.

Although sleep deprivation appeared to affect steering performance—the participants exhibited considerably more variability in lane position on the fourth drive which occurred at night than they did in their first drive in the morning (at 8:00 a.m. or 9:00 a.m.)—sleep deprivation was *not* found to affect the braking patterns of the drivers as they approached the stop-controlled intersections.

The first two studies of this series investigated the effect of rumble strips on stopping behavior at simulated rural controlled intersections—in the first study with attentive drivers and in the second with drivers who were sleep deprived. In both studies, the presence of rumble strips affected the braking pattern of the drivers as they approached the intersections. Despite their fatigue, the drivers braked earlier and to a greater extent when they were further away from intersections *with* rumble strips, than they did when approaching intersections *without* rumble strips.

The results of this study parallel those obtained in the first study. Nevertheless, these results should not be interpreted as definitive with regard to the role of rumble strips in facilitating stopping behavior. The third study, which has just begun, will help to complete our understanding of the way in which rumble strips affect the stopping behavior of drivers at real-world intersections at various locations in Minnesota. We will compare the stopping behavior that occurs at similar intersections, *with* and *without* rumble strips. We will investigate a number of intersections with varying features (e.g., sightlines and topography). In summary, the first two studies are important contributions to the existing body of knowledge regarding the role that rumble strips have on stopping behavior at stop-controlled intersections. Upon completion of the third study we will have a more complete understanding of their effectiveness. Considered together the three studies should provide a sound basis on which to offer recommendations for the use of rumble strips.

CHAPTER 1
INTRODUCTION

This is the second in a series of three studies conducted by the authors to investigate various aspects of in-lane (transverse) rumble strips. The Manual on Uniform Traffic Devices (MUTCD, 2001) defines rumble strips as “intermittent, narrow, transverse areas of rough-textured or slightly raised or depressed road surface” (MUTCD, 2001, page F-64). They are used to “alert drivers to unusual motor traffic vehicle conditions through noise and vibration” in order to attract their “attention to such features as changes in alignment and conditions requiring a stop” (MUTCD, 2001, page F-64). All three studies in the series focus on the latter usage.

The first in the series of studies (Harder, Bloomfield & Chihak, 2001) confirmed the belief of many (both professionals and lay people) that rumble strips warn drivers of an upcoming traffic control device or changes in road conditions. In an experiment that utilized a driving simulator, Harder *et al* showed that rumble strips affected the *braking pattern* of the driver; the experimental participant used the brakes to a greater extent *earlier* in the slowdown process than if there was no rumble strip.

Prior to the Harder *et al* study, no empirical work had indicated whether or not in-lane rumble strips are actually helpful as warning devices. The field studies that had been conducted were inconclusive or were methodologically flawed. Interestingly, soon after the Harder *et al* study was published, Fitzpatrick, Brewer, and Parham (2002) compared the speed on 14 approaches to rural intersections near Abilene and Gatesville, in Texas, *before* and *after* rumble strips were installed. Fitzpatrick *et al* confirmed the results of the Harder *et al* study—reporting that there was “a less gradual deceleration for drivers in the *after* period” (p. 3) than there was *before* the rumble strips were installed.

At this time, lay knowledge is used to determine whether rumble strips should be implemented at a particular intersection. Apart from the Harder *et al* and Fitzpatrick *et al* studies, we are not aware of other literature that could serve as a guide on the topic. However, the Harder, et al. study did not test for inattentive or fatigued drivers and the state of the drivers observed in the Fitzpatrick *et al* is not known.

Despite the paucity in literature on the effectiveness of in-lane rumble strips, a recent survey conducted by SRF Consulting Engineers revealed that 56 of the 68 Minnesota counties that responded to their survey use rumble strips (Corkle, Marti, and Montebello, 2001). Many of the responding counties use in-lane rumble strips at all paved intersections that have a STOP sign. Despite their extensive use, in-lane rumble strips are not listed in the Manual of Uniform Traffic Control Devices as a traffic control device. Solid research is needed to inform county engineers about the utility of rumble strips at problem intersections. It is anticipated that the current study, the second in the series, will yield useful information regarding the effect of in-lane rumble strips on the stopping performance of sleep-deprived drivers.

As mentioned above, in the first study (Harder *et al*, 2001), the lone effect of rumble strips was observed in the braking pattern. We found that drivers brake more, and earlier, as they approach the intersection if rumble strips are installed than they do if there are no rumble strips. However, it should be emphasized that the effect was on *braking*—experimental participants applied their foot to the brake earlier in the presence of rumble strips. Also, neither the presence nor absence of rumble strips affected the point at which drivers removed their foot from the accelerator (and started to slow down), or the point at which they stopped their vehicle. Results also revealed that drivers brake more, and earlier, when full coverage rumble strips are in place than they do when wheel track rumble strips are installed.

It should be noted that the participants in Harder *et al*'s study were *attentive* drivers. The objective of the current study, the second study in the series, was to investigate the effect of in-lane rumble strips on the stopping performance of *sleep-deprived* drivers. [The study was nested in a larger fatigue study and thus has components that are not directly related to an investigation of the effects of rumble strips.] In this study twenty commercial motor vehicle drivers were tested over a twenty-hour period, during which they were kept continuously awake. During this period they drove in a driving simulator for approximately one hour four times throughout the day—in the morning, the afternoon, the evening and at night.

CHAPTER 2
METHOD

2.1 Participants

The experimental design called for 20 subjects. Twenty-five commercial vehicle drivers took part in study. The data from five subjects were not used for the following reasons—(1) one subject (the first) was used as a pilot subject; (2) on one weekend, because a change was made to the simulator software on the day prior to testing, data from three subjects could not be recovered; and (3) the data from one subject were excluded because he missed so much sleep before taking part in the study that his data in all four drives were atypical. These subjects were replaced, so that we obtained data from 20 drivers, as planned. Of the final 20 subjects from whom we obtained data, 18 were male and two were female.

The subjects were recruited with the help of the Minnesota Trucking Association (MTA). The MTA informed their members by email that a study of the effects of fatigue on driving was to be conducted at the University of Minnesota. All drivers who were interested in the study were first screened, using the screening questions presented in Appendix 1. The selected subjects were between the ages of 25 and 60 years, had 20/20 vision (with corrective lenses, if necessary), a current driver's license and at least three years of driving experience. Potential subjects were excluded from the study if they suffered from migraines or severe tension headaches, experienced motion sickness in automobiles, airplanes, or on amusement park rides, if they felt queasy at IMAX presentations, if they had been diagnosed with a sleep disorder, or if they were pregnant or breast feeding.

2.2 The Driving Simulator

A more advanced driving simulator than that available for the first study in this series was used. Its key components are described below.

2.2.1 Driving Simulator Vehicle

The driving simulator vehicle was a full-body 2002 Saturn SC1 coupe.

2.2.2 Driving Simulator Visuals

When seated in the simulator vehicle, each participant had a 210-degree forward field-of-view—provided by five flat-panel screens that each measured 4.7-ft (1.433-m) high by 6.5-ft (1.981 m) wide. There was a central flat panel in front of the simulator vehicle. The center of this panel was aligned with the line of sight of the driver of the simulator vehicle. Two intermediate panels flanked the central panel, to the left and right. The two intermediate panels were set at 138 degrees to the central panel. Two outer panels—one on the right, the other on the left—were set at 138 degrees to the intermediate panels. The base of all five flat-panel screens was elevated 1.333 ft (0.064 m) above the floor. Five projectors were used to project a coordinated, high-fidelity, virtual environment onto the five flat-panels that comprised the 210-degree forward field-of-view. The simulator provided rear-view imagery in two ways. First, there was a 10-ft (3.048-m) high by 7.5-ft (2.286-m) wide screen that was mounted behind the vehicle that the driver could see through the vehicle's rear-view mirror. Second, two 5-inch (12.7 cm) LCD screens were installed in place of the simulator vehicle's side-view mirrors. Coordinated imagery was presented through the five-forward and three rear-view channels.

2.2.3 Driving Simulator Vehicle Controls

The driving simulator's controls were equipped with sensors that relayed to the driving simulator computer the participant's inputs to the steering wheel, transmission, and the accelerator and brake pedals. The driving simulator computer provided a real-time interface with the virtual environment. Force feedback was applied to the steering wheel, using a high-torque motor attached to the steering column. A vacuum assist pump was connected to the brake pedal in order to simulate realistic braking. The driving simulator vehicle was equipped with an automatic transmission interface, which was functional and was controlled by the driving simulator computer.

2.2.4 Driving Simulator Sound System

Road and traffic noise, and the driving simulator's engine sounds were delivered through four speakers placed around the vehicle's exterior near the base of the five panels that comprised the forward view. Each speaker received independent inputs from the simulator's 3D sound generation system. Low-frequency sounds were delivered using a ten-inch subwoofer located inside the simulator vehicle's engine compartment. If necessary, the experimenter could communicate with each participant via a dedicated intercom system that made use of four speakers installed in the simulator vehicle's factory speaker locations.

2.2.5 Driving Simulator Vehicle Movement

A bass shaker mounted to the underside of the vehicle's frame provided additional low-frequency vibration.

2.2.6 Rumble Strip Dynamics

A set of two full-coverage (covering the lane width) virtual in-lane rumble strips were used on the intersection approach with rumble strips. When the front wheels of the car touched the virtual rumble strips, an auditory cue simulating the sound of a rumble strip was sent through the driving simulator's audio system; the steering wheel vibrated as well at a frequency of 10 HZ. The vibrating steering wheel and rumble strip sound occurred simultaneously while the car passed over each of the two rumble strips.

2.2.6 Data Recording

The virtual position of the simulator vehicle, relative to the scenario the participant was driving, was recorded at a rate of 20 Hz throughout each experimental drive. From this record, it was possible to determine the participant's steering performance and the speed at which he or she was driving the vehicle. In addition, three micro-video cameras positioned in the cab of the simulator vehicle were used to record (i) the participant's face, (ii) his or her foot position, and (iii) his or her steering wheel responses throughout the course of each experimental session. A video display at the experimenter's station enabled the experimenter to monitor the subject throughout each session.

There was no working clock or radio in the vehicle. The radio was not permitted as it had the potential to be a confounding variable. If different subjects had heard different programs or music on different trials, there may have been a variety of uncontrolled influences on the way in which they drove.

2.3 Experimental Design

A within-subjects design was used which means that each participant experienced all of the experimental conditions. Each participant drove in the test route of 59.53 miles (95.803 km) four times—in the morning, afternoon, evening, and at night. Before and after each drive the participants were tested with an EyeCheck™ device. In addition, between drives a battery of tests was administered—the battery consisted of a Snellen-equivalent acuity test, a contrast sensitivity test, a psycho-motor vigilance test, and a code substitution test.

2.4. The Test Route

The subjects drove for 59.53 miles (95.803 km) on the route shown in Figure 2.1.

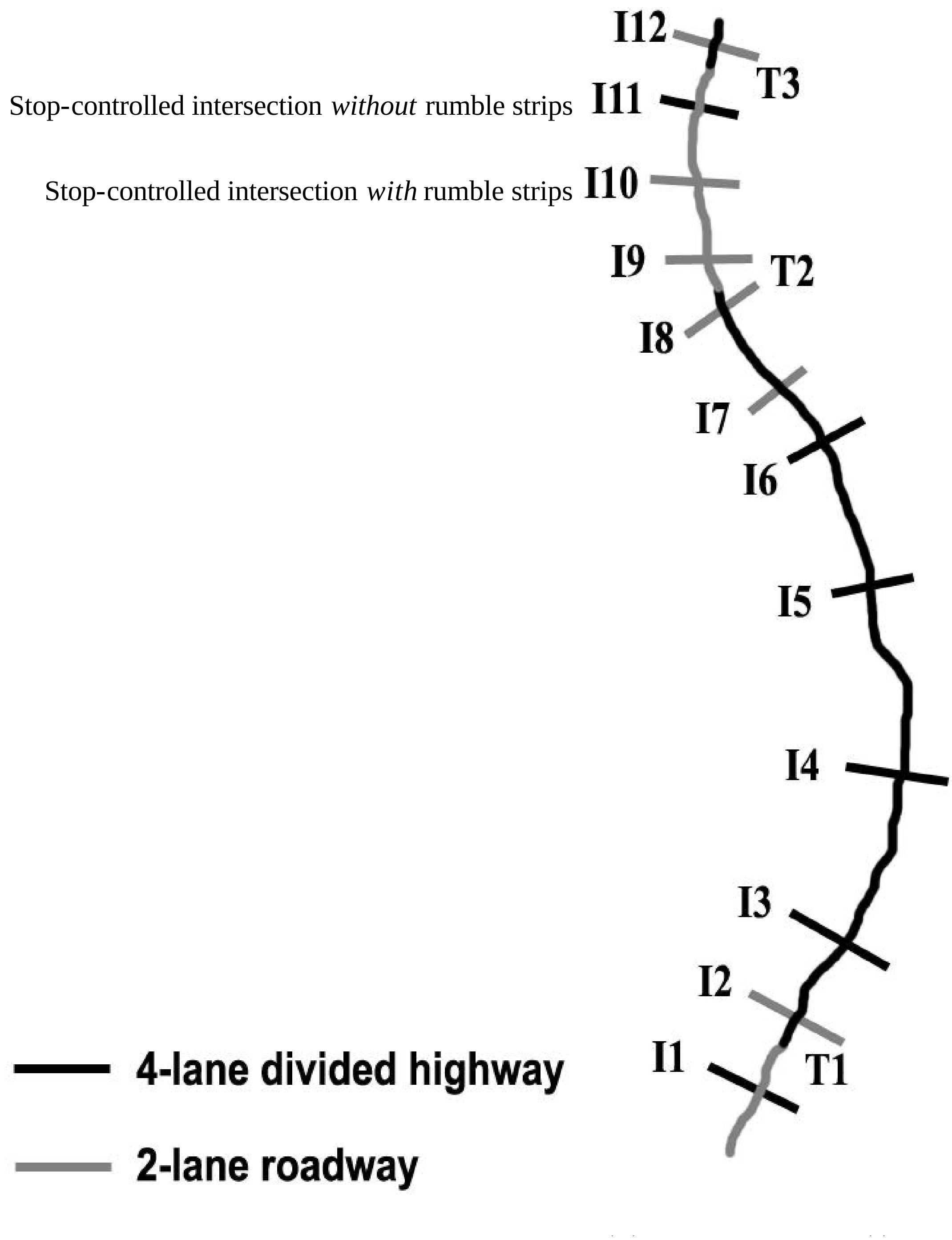

Figure 2.1. The test route.

As Figure 2.1 shows, the route consisted of a long section of 4-lane divided highway (with two lanes in each direction and a median between them), then a shorter section of 2-lane road (with one lane in each direction), and finally another brief section of 4-lane divided highway. A key to the features of the road (road transitions and intersections) is presented in Table 2.1.

Table 2.1: Key to features [T = road transitions; I = intersections] indicated in Figure 2.1—with distance of each feature from previous feature and from the start of the drive.

Key	Feature	Distance from Previous Feature	Distance from Start
T1	Start of drive	0	0
I2	1st traffic light	3,153 m (1.96 miles)	3,153 m (1.96 miles)
I3	overpass	7,618,m (4.73 miles)	10,771 m (6.89 miles)
I4	overpass	16,204 m (10.07 miles)	26,975 m (16.76 miles)
I5	overpass	17,338 m (10.77 miles)	44,313 m (27.53 miles)
I6	overpass	13,147 m (8.17 miles)	57,460 m (35.70 miles)
I7	overpass	6,007 m (3.73 miles)	63,467 m (39.44)
I8	2nd traffic light	9,029 m (5.61 miles)	72,496 m (45.05 miles)
T2	End 4-lane divided/Start 2-lane	1,629 m (1.01 miles)	74,125 m (46.06 miles)
I9	3rd traffic light	2,886 m (1.79 miles)	77,011 m (47.85 miles)
I10	Stop—with rumble	6,563 m (4.08 miles)	83,574 m (51.93 miles)
I11	Stop—no rumble	7,061 m (4.39 miles)	90,635 m (56.32 miles)
T3	End of 2-lane/Start of 4-lane divided	3,515 m (2.18 miles)	94,150 m (58.50 miles)
I12	End of drive	1,653 m (1.03 miles)	95,803 m (59.53 miles)

As Figure 2.1 shows and Table 2.1 indicates, each subject drove on a 4-lane divided highway, starting at T1. In this section of highway, the subject encountered a traffic light at I2, 1.96 miles (3.153 km) from the start of the drive, and five overpasses with exit and entry ramps at points I3, I4, I5, I6, and I7, before encountering a second traffic light at I8, 45.05 miles (72.496 km) from the start of the drive. This section of 4-lane divided highway ended 46.06 miles (74.125 km) from the start of the drive.

When the first section of 4-lane divided highway ended, again as Figure 2.1 shows and Table 2.1 indicates, at T2 the road changed to a 2-lane road. In the 2-lane section of the route, the subject encountered a third traffic light at I9—after driving on the 2-lane road for 1.79 miles (2.886 km) and after driving 47.85 miles (77.011 km) from the start of the drive—and two stop-sign controlled intersections. At the first of these stop-sign controlled intersections, at I10, a set of two *rumble strips were installed*—this intersection occurred 5.87 miles (9.449 km) into the 2-lane section and 51.93 miles (83.574 km) from the start of the drive. *Rumble strips were* <u>*not*</u> *installed* at the second of these stop-controlled intersections, at I11—this intersection occurred 10.26 miles (16.510 km) into the 2-lane section and or 56.33 miles (90.635 km) from the start of the drive. The 2-lane section of the route was 12.44 miles (20.025 km) in length.

When the 2-lane section of the drive ended, there was a second brief section of 4-lane divided highway. After 1.03 miles (1.653 km) there was another intersection—I12. The subject was asked to stop just before this intersection, having driven 59.53 miles (95.803 km) from the start of the drive.

2.5 Test Battery

In addition to driving in the simulator, each participant was presented with the following battery of tests. As noted above, this study was nested in a larger fatigue study. The test battery was a component of the fatigue study, not the rumble strip study. Nevertheless, details are presented here to portray the complete experience of the participants during their time in the laboratory.

2.5.1 EyeCheck™ Device

The EyeCheck™ device is a pupillometer. It resembles a pair of binoculars and was used in this study to measure the pupil diameter of each participant before and after he or she drove in the simulator. The EyeCheck™ device projects a beam of infrared light into the participant's pupil and measures the amount of the infrared light that is reflected back from the participant's retina through the pupil. From this information it is possible to calculate the size of the pupil. When the device was used in this study, the participant held it up to his or her eyes and fixated on a red cross. After fixating on the red cross for 30 seconds, a controlled green flash was directed into the pupils and the device recorded the subsequent change in pupil size and the rapidity of that change. Specifically, the device measured the time in milliseconds from the beginning of the flash to the moment that the pupil started to constrict, the time in milliseconds until full constriction occurred, the reduction in pupil size and then, after full constriction, the time taken for the pupil to recover (i.e., until the pupil size reached an asymptote), and the pupil size when it recovered. Each participant was tested with the EyeCheck™ device immediately before and after each of the four times the participant drove in the simulator.

2.5.2 Snellen-Equivalent Acuity

A Ferree and Rand chart was used to determine whether there was any change in the visual acuity of the participants over the course of the experimental session. There is a series of black circles on the chart that are systematically reduced in size from line to line. There is a break on each circle. The break appears in one of the following eight locations—(1) top; (2) top left; (3) to the left; (4) bottom left; (5) bottom; (6) bottom right; (7) right; and (8) top right. The participant's task was to state where the break occurred in each circle. Each participant was tested four times with the Ferree and Rand chart—(1) after the first drive in the simulator; (2) before the second drive; (3) before the third drive; and (4) before the fourth drive.

2.5.3 Contrast Sensitivity Test

A Pelli-Robson chart was used to determine any change in the contrast sensitivity of each participant that might have occurred throughout the course of the experimental session. The chart has on it a series of large letters of different shades of gray. There are six letters per line. The contrast of each letter against the white background on which it is presented is systematically reduced from the top left of the chart to the bottom right. The participant's task was to read the chart, naming each of the letters until he or she could no longer detect them. Each participant was tested four times with the Pelli-Robson chart: (1) after the first drive in the simulator; (2) before the second drive; (3) before the third drive; and (4) before the fourth drive.

2.5.4 Psychomotor Vigilance Test (PVT)

In this study, we also administered the psychomotor vigilance test developed by Wilkinson and Houghton (1982) and Dinges and Powell (1985). The test has been used in several fatigue studies. Each participant held the device and looked at its small screen. The task of the participant was to press a response button as quickly as possible whenever a trial began. Red numbers appeared on the screen at the start of each trial. The numbers rapidly increased because they count the number of milliseconds since the onset of the trial. The trial ended as soon as the participant pressed the response button. The interval between the end of one trial and the start of the next was randomly varied. The psychomotor vigilance test took ten minutes, and each participant was tested with it four times: (1) after the first drive in the simulator; (2) before the second drive; (3) before the third drive; and (4) before the fourth drive.

2.5.5 Code Substitution Test

The code substitution test was administered using a computer. The participant looked at the computer screen. At the top of the screen, he or she saw a series of letter and number pairs, with the letter above the number. Below each letter, there was a number in parentheses. Lower on the screen a second series of letters appeared, but below them there were only parentheses. The participant's task was to look at each letter in this second series, then to look up to the top of the screen and find the same letter and the number paired with it, and then to use the number pad on the computer to insert the matched number in the parentheses underneath the letter lower in the screen. As soon as the participant had done this, he or she moved on to the next letter in the series and repeated the procedure. As soon as the participant had added numbers below all the letters in the lower series, the screen was cleared. And immediately a different set of paired letters and numbers appeared at the top of the screen—the second series of letters lower on the screen was also different. The code substitution test also took ten minutes to complete, with each participant tested four times—(1) after the first drive in the simulator; (2) before the second drive; (3) before the third drive; and (4) before the fourth drive.

2.6 Experimental Procedure

The experimental procedure had three parts—an initial contact made by telephone, a screening visit, and the main study. They are detailed below.

2.6.1 Initial Contact

First, the Minnesota Trucking Association informed their member trucking companies that a study of the effects of fatigue was to be conducted. Then, potential participants contacted us, by phone or in a few cases by email. They were given information about the study—particularly its length. If they were interested in participating, they were asked the screening questions that are presented in Appendix 1. Then, each of those who were eligible for the study and who were able to fit the study into their schedule, made appointments to visit the facility for the screening visit and the main study.

2.6.2 Screening Visit

The screening visit took place approximately one week before the main study. After reading and signing a consent form for the screening visit, each potential participant was again asked the screening questions presented in Appendix 1. Then, he or she drove for approximately ten minutes in the driving simulator. One participant felt queasy and stopped driving before the end of the ten minutes. He did not take part in the main study. After the test drive in the simulator, the other participants who were screened were given an Actiwatch and asked to wear it until they returned for the main study. They were also asked to fill out a sleep diary each day before the main study. The sleep diary is presented in Appendix 2. Then the session, which took approximately 40 minutes, ended.

2.6.3 Main Study

The main study was conducted on Fridays, Saturdays, or Sundays. On eleven occasions, one participant was tested per day in the main study—this included nine participants from whom data are reported as well as the pilot participant and one of the three participants whose data could not be recovered. On seven occasions, two participants were tested per day in the main study—this included eleven participants from whom data are reported as well as two of the three participants whose data could not be recovered and the participant whose data were excluded because they were atypical on all of the drives. When there was only one participant tested per day, the session began at 8:30 a.m. On the days when two participants took part in the study per day, the first participant began at 7:30 a.m., with the second following at 8:30 a.m.; the test procedure was the same for both participants, except for the shift in time of one hour. Below, the procedure followed by each participant is illustrated (for a participant arriving at 8:30 a.m.). [Please note all times are approximate.]

8:00 a.m. (Day 1)—The participant arrived at the driving simulator facility and gave an experimenter the sleep diary and the Actiwatch. Then, the participant read and signed a consent form for the main study.

8:40 a.m. (Day 1)—The participant was tested with the EyeCheck™ device.
8:50 a.m. (Day 1)—The participant took a practice drive in the driving simulator. During this practice drive, which lasted approximately ten minutes, an experimenter sat in the vehicle with the participant. The drive began on a 4-lane divided highway, and then transitioned to a 2-lane road. During the practice drive, the experimenter asked the participant to switch lanes, from right to left, and back again, three times. Also during the drive, the experimenter instructed the participant to practice stopping in a normal fashion and to make an emergency stop.

9:00 a.m. (Day 1)—The experimenter got out of the simulator vehicle. Then, the first test drive began. The participant was asked to drive the 59.53-mile (95.803-km) test route as he or she "normally would if you were driving the same road in the real world."

10:00 a.m. (Day 1)—The first test drive ended. The participant got out of the simulator vehicle. The participant was tested with the EyeCheck™ device. Then, an experimenter administered the battery of tests to the participant in the following order—(1) the Contrast Sensitivity test; (2) the Code Substitution test; (3) the PVT; and (4) the Snellen-Equivalent acuity test.

12:00 noon(Day 1)—Lunch was provided for the participant from a local restaurant. [Typically, the participant walked with an experimenter to the restaurant, then brought the meal back to the participant room in which they spent most of their time between testing periods.]

2:30 p.m. (Day 1)—An experimenter administered the battery of tests to the participant in the following order—(1) the Snellen-Equivalent acuity test; (2) the PVT; (3) the Code Substitution test; and (4) the Contrast Sensitivity test. Then the participant was tested with the EyeCheck™ device.

3:00 p.m. (Day 1)—The second test drive began. Again, the participant was asked to drive the test route as he or she "normally would if you were driving the same road in the real world."

4:00 p.m. (Day 1)—The second test drive ended. The participant got out of the simulator vehicle, and then was tested with the EyeCheck™ device.

6:00 p.m. (Day 1)—Dinner was provided for the participant from a local restaurant. [Again typically, the participant walked with an experimenter to the restaurant, and brought the meal back to the participant room.]

8:30 p.m. (Day 1)—An experimenter administered the battery of tests to the participant in the following order—(1) the Snellen-Equivalent acuity test; (2) the PVT;

(3) the Code Substitution test; and (4) the Contrast Sensitivity test. Then the participant was tested with the EyeCheck™ device.

9:00 p.m. (Day 1)—The third test drive began, with the participant asked to drive as he or she "normally would if you were driving the same road in the real world."

10:00 p.m. (Day 1)—At the end of the third test drive, the participant was tested with the EyeCheck™ device.

12:00 midnight—Snacks were provided for the participant in the participant room.

2:30 a.m. (on Day2)—Once again, an experimenter administered the battery of tests to the participant in the following order—(1) the Snellen-Equivalent acuity test; (2) the PVT; (3) the Code Substitution test; and (4) the Contrast Sensitivity test. Then the participant was tested with the EyeCheck™ device.

3:00 a.m. (on Day2)—The fourth test drive began, with the participant asked to drive as he or she "normally would if you were driving the same road in the real world."

4:00 a.m. (on Day2)—At the end of the fourth test drive, the participant was tested with the EyeCheck™ device. Then, the participant was driven to the General Clinical Research Center (GCRC).

12:30 p.m. (on Day2)—The participant was discharged from the GCRC, and driven home by a friend, by a relative, or by taxi.

CHAPTER 3
RESULTS AND DISCUSSION

3.1 Braking Pattern

As already mentioned, Harder *et al* (2001)—in the first in this series of studies—found that attentive drivers used their brakes to a greater extent *earlier* in the slowdown process at intersections *with* rumble strips than they did at intersections *without* rumble strips. And, then in a subsequent field study in Texas, Fitzpatrick *et al* (2002) confirmed these results when they found that drivers were braking earlier *after* rumble strips had been installed at intersections than they were *before* the installation.

In order to examine the braking pattern of the participants in the current study, the approach to the intersections *with* and *without* rumble strips were segmented—then the mean speed in each of the segments was determined, so that the speeds on the two approaches could be compared. The approaches were segmented as shown in Table 3.1. It is important to note that the approach to the intersection *without* rumble strips was segmented in the same way that the approach to the intersection *with* rumble strips, allowing direct segment-by-segment comparison between the approaches to both intersections.

Table 3.1: Segmentation of approach to stop-controlled intersections

Segment Number	Segment Location (in meters and feet relative to the edge line at the intersection)
1	418-368 (1,371.4 – 1,207.3 ft)
2	368-318 (1,207.3 – 1,043.0 ft)
3	318-293 (1,043.0 – 961.3 ft)
4	293-268 (961.3 – 879.3 ft)
5	268-243 (879.3 – 797.2 ft)
6	243-218 (797.2 – 715.2 ft)
Location of first rumble strips	218 (715.2 ft)
7	218-193 (715.2 – 633.2 ft)
8	193-168 (633.2 – 551.2 ft)
9	168-143 (551.2 – 469.2 ft)
10	143-118 (469.2 – 387.1 ft)
Location of second rumble strips	118 (387.1 ft)
11	118-93 (387.1 – 305.1 ft)
12	93-68 (305.1 – 223.1 ft)
13	68-43 (223.1 – 141.1 ft)
14	43-18 (141.1 – 59.1 ft)
15	18 (59.1 ft) - stopping point

Next, for each driver in all four drives, we determined the mean speed in each of the segments shown in Table 3.1, both for the approach to the intersection *with* rumble strips and the intersection *without* rumble strips. An ANOVA was used to analyze these mean speed data—the summary of this analysis is presented in Table 3.2.

Table 3.2: Summary of ANOVA conducted on mean speeds in the fifteen segments on the approach to the intersection *with* rumble strips and the intersection *without* rumble strips

Source of Variance	**Degrees of Freedom**	**Mean Squares**	**Variance Estimate**	**F-Value**	***p*-Value**
Subjects (S)	19	217988.193	11473.063		
Rumble Strips (With vs. Without) (R)	1	6289.666	6289.666	16.376	**0.0007**
Interaction S x R	19	7297.699	384.089		
Between Drives (D)	3	1484.572	494.857	0.652	0.5848
Interaction S x D	57	43239.580	758.589		
Between Segments (SEG)	14	1525413.275	108958.091	466.932	**<0.0001**
Interaction S x SEG	266	62070.851	233.349		
Interaction R x D	3	552.253	184.084	0.918	0.4379
Interaction S x R x D	57	11425.886	200.454		
Interaction R x SEG	14	12062.235	861.588	15.344	**<0.0001**
Interaction S x R x SEG	266	14946.279	56.189		
Interaction D x SEG	42	3313.056	78.882	1.892	**0.0007**
Interaction S x D x SEG	798	33266.806	41.688		
Interaction R x D x SEG	42	1585.027	37.739	1.198	0.1850
Interaction S x R x D x SEG	798	25130.303	31.492		

Table 3.2 indicates that there were two statistically significant main effects. First, there was a statistically significant difference in the mean speeds on the approach to the intersection with rumble strips and the approach to the intersection without rumble strips (p=0.0007); second there was a statistically significant difference in mean speeds between the segments on the intersection approaches (p<0.0001). In addition, Table 3.2 shows that there were two statistically significant interactions—one an interaction between the two significant main effects, intersection type (rumble strips vs. no rumble strips) and segments (p<0.0001), and the other between drives and segments (p=0.0007).

The main effects due to intersection type (rumble strips vs. no rumble strips) and to segments, as well as the interaction between them are examined in Figure 3.1.

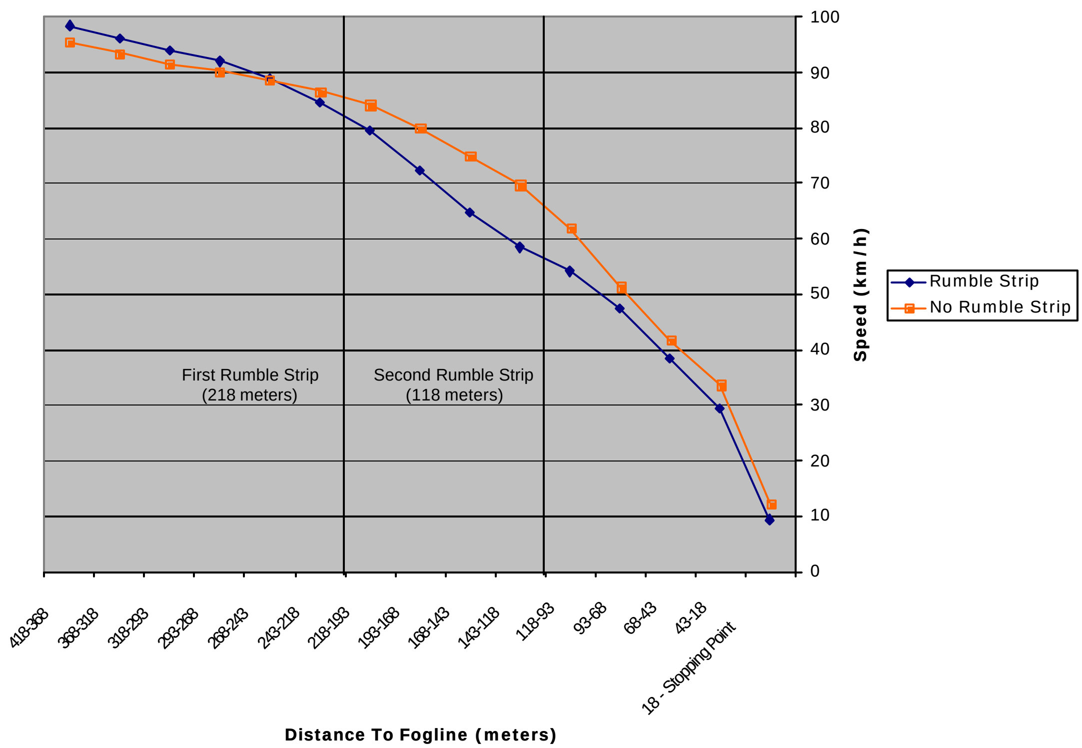

Figure 3.1: The difference in mean speeds for the fifteen segments on the approach to the intersection *with* rumble strips and the intersection *without* rumble strips

The effect of segments can be seen clearly in Figure 3.1—as the driver approached both intersections, the mean speed in the segments progressively decreased.

The interaction between intersections and segments is also very clear in Figure 3.1. And, it should be noted, that this interaction is the key finding in this study. First, for the six segments [418 meters (1,371.4 ft) to 218 meters (715.2 ft) from the intersection] *before* the rumble strips occurred, there is no statistically significant difference in mean speeds.

After the rumble strips occur, 218 meters (715.2 ft) from the intersection, the braking patterns are statistically significantly different for the two intersections. For the next five segments [218 meters (715.2 ft) to 93 meters (305.1 ft) from the intersection], the mean speeds for the intersection *with* the rumble strips are slower than the mean speeds for the intersection *without* the rumble strips—over these segments the participants used their brakes more on the approach to the intersection *with* rumble strips than on the approach to the intersection *without* rumble strips.

Finally, for the last four segments [covering the last 93 meters (305.1 ft) to the intersection], although there is a decrease in the difference in the mean speeds for the two intersections, there is still a statistically significant difference in the speeds—the mean speeds for the intersection *with* the rumble strips are slower than those for the intersection *without* the rumble strips.

In summary, it is clear from Figure 3.1 that the difference in speeds began at the point that the rumble strips occurred, and that the *presence* of the rumble strips caused the drivers to change their braking pattern by braking to a greater extent earlier in the approach.

The second interaction, between segments and drives, is examined in Figure 3.2.

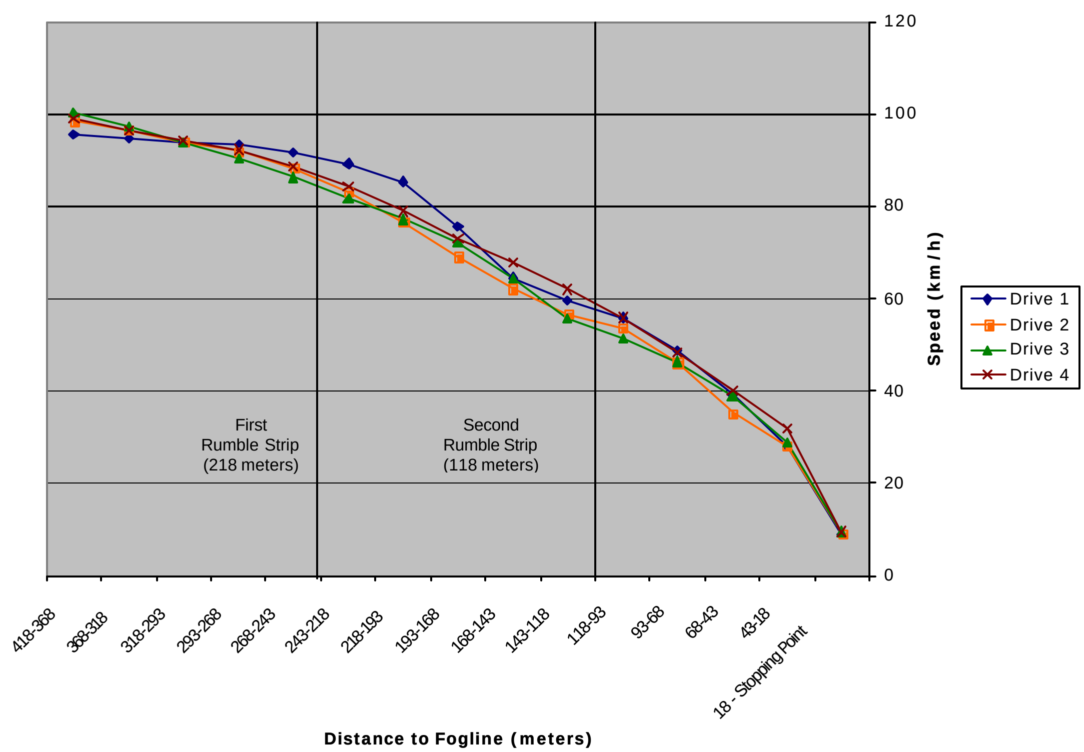

Figure 3.2: The difference in mean speeds collapsed across the two approaches (*with* and *without* rumble strips) for the fifteen segments on the four drives

Figure 3.2, like Figure 3.1, clearly shows the reduction in intersection approach speeds—as the driver approached the intersections, the mean speed in the segments progressively decreased. The figure also shows the interaction between drives and segments; the participants drove faster on the fifth, sixth, seventh, and eighth segments [when they were

268 meters (879.3 ft) to 168 meters (551.2 ft) from the intersections] on the first drive than they did on the subsequent three drives. The difference between the speed for the first drive and the subsequent three drives suggests that the participants adjusted their behavior when they became more familiar with the test route.

3.2 Beginning of Slowdown

In the first study of the series, we did not find a difference in the point at which the drivers began to slowdown (Harder *et al*, 2001). We carried out a similar comparison in the current study. We determined the point at which each driver began to slow down (i.e., take his/her foot off the accelerator) on the approach to the intersection *with* rumble strips and the intersection *without* rumble strips for each of the twenty participants on each of their four drives—in the morning, the afternoon, the evening, and at night. An analysis of variance (ANOVA) was conducted on these data. The results of this analysis are summarized in Table 3.3.

Table 3.3: Summary of ANOVA conducted on point at which driver began to slow down (i.e., took foot off accelerator)

Source of Variance	**Degrees of Freedom**	**Mean Squares**	**Variance Estimate**	**F-Value**	***p*-Value**
Subjects (S)	19	1550016.713	81579.827		
Rumble Strips (With vs. Without) (R)	1	136326.492	136326.492	7.553	**0.0128**
Interaction S x R	19	342940.072	18049.477		
Between Drives (D)	3	124950.587	41650.196	3.582	**0.0192**
Interaction S x D	57	662781.108	11627.739		
Interaction R x D	3	43858.995	14619.665	1.837	0.1507
Interaction S x R x D	57	453609.839	7958.067		

Table 3.3 indicates that there were two statistically significant main effects. First, there was a difference in the point at which the driver took his or her foot off the accelerator (began to slow down) for the intersection approach *with* rumble strips and the intersection approach *without* rumble strips (p=0.0128); and second, there were differences in the point at which the driver began to slow down between the four drives (p=0.0192). The first of these significant differences—the point at which the participants began to slow down—is shown in Table 3.4.

Table 3.4: Mean distance in meters (and feet) from each intersection at which drivers began to slow down (i.e., took foot off accelerator)

***With* Rumble Strips**	***Without* Rumble Strips**	**Difference**
356.636 (1,170.07 ft)	415.015 (1,361.6 ft)	58.379 (191.53 ft)

Table 3.4 shows that the drivers began to slow down, by taking their foot off the accelerator 58.379 meters (191.53 ft) earlier for the intersection *without* rumble strips than they did for the intersection *with* rumble strips. The most likely explanation for this difference from the Harder *et al* study is that, for the current study, the two intersections were not identical. The cross road for the intersection *with* rumble strips was a two-lane undivided highway, while the cross road for the intersection *without* rumble strips was a four-lane divided highway. The latter cross road likely provided more cues to the driver that he or she was approaching an intersection.

When this result is considered along with the difference in braking patterns revealed in Figure 3.1, it is striking that, in the spite of the fact that they began to slow down earlier when approaching the intersection *without* rumble strips—and were thus able to anticipate the intersection while further away from it—the participants were braking earlier and to a greater extent for the intersection *with* rumble strips.

The second of the significant differences, in the point at which the driver began to stop due to drives, is shown in more detail in Table 3.5

Table 3.5: Mean distance in meters (and feet) at which drivers began to slow down (i.e., took foot off accelerator) for each drive

Drive	**Distance**
1st Drive	360.521 (1,182.81 ft)
2nd Drive	375.958 (1,233.46 ft)
3rd Drive	373.683 (1,225.99 ft)
4th Drive	433.140 (1,421.06 ft)

Table 3.5 shows that, in general, for the later drives the participants began to slow down more when they were further away from the intersections. For the first drive, the average point at which the participants began to slow down was just over 360 meters (1,181.1 ft) from the intersection; this increased to nearly 376 meters (1,233.64 ft) and 374 meters (1,227.0 ft) for the second and third drives, and to slightly over 433 meters (1,420.6 ft) for the fourth drive. The explanation for this trend towards increasing the distance at which the drivers began to slow down suggests that there was a learning effect as the drivers became more familiar with the test route.

3.3 Stopping Point

The point at which each driver stopped relative to the edge line on the cross road at the intersection *with* rumble strips and the intersection *without* rumble strips was determined for each of the twenty participants on each of their four drives—one in the morning, one in the afternoon, one in the evening, and one late at night. An analysis of variance (ANOVA) was conducted on these data. The results of this analysis are summarized in Table 3.6.

Table 3.6: Summary of ANOVA conducted on point at which driver stopped

Source of Variance	**Degrees of Freedom**	**Mean Squares**	**Variance Estimate**	**F-Value**	***p*-Value**
Subjects (S)	19	25.377	1.336		
Rumble Strips (With vs. Without) (R)	1	45.895	45.895	4.771	**0.0417**
Interaction S x R	19	182.776	9.620		
Drives (D)	3	0.317	0.106	0.082	0.9696
Interaction S x D	57	73.432	1.288		
Interaction R x D	3	6.668	2.223	1.647	0.1893
Interaction S x R x D	57	77.042	1.352		

Table 3.6 indicates that the point at which the driver stopped was statistically significantly different for the two intersections (p=0.0417). The extent of the effect is shown in Table 3.7.

Table 3.7: Mean distance in meters (and feet) that the participants stopped from each intersection

With **Rumble Strips**	***Without*** **Rumble Strips**	**Difference**
6.596 (21.64 ft)	5.525 (18.13 ft)	1.071 (3.51 ft)

As Table 3.7 shows, the participants stopped 1.071 meters (3.51 ft) further back from the edge line of the crossing road for the intersection *with* rumble strips. The finding that the participants stopped further back from the intersection *with* rumble strips than they did from the intersection *without* rumble strips is likely to improve safety.

3.4 The Effect of Sleep Deprivation on Steering Variability

Interestingly, the stopping patterns shown in Figure 3.2 above did not change as a function of the drive itself—in other words sleep deprivation did not affect the drivers' braking patterns at either intersection on the four drives. Since the drivers' stopping patterns for the four drives were *not* significantly different, the experiment gave no indication that sleep deprivation affected the stopping performance of the participants—not even when they approached the intersections in their fourth drive (which began at 2.00 a.m. or 3.00 a.m., after they had been participating in the study for 18.5 hours). Because fatigue did not appear to affect the driver's stopping patterns on the four drives, we are including the analysis of steering variability. The results of the analysis show that driver fatigue affected steering variability—the drivers' steering was more unstable in the entire route during the fourth drive. This is a clear indication of driver impairment. More details of the analysis are given below.

In order to analyze steering performance, the 59.53-miles (95.803-km) test route was divided into seven sections. The driving conditions varied between the sections (e.g., whether the speed limit was 55 mph or 65 mph, whether the section was a 4-lane divided highway or a 2-lane undivided highway, etc.). After the test route was divided into sections, the variability in steering performance (i.e., standard deviation of mean lane position of the driver's vehicle) was calculated for each participant as he or she drove each section of the route in each of the four drives—this follows the method of determining steering performance suggested by Bloomfield and Carroll (1996). An ANOVA was conducted on the steering variability data—the summary of this ANOVA is presented in Table 3.8.

Table 3.8: Summary of ANOVA conducted on steering performance

Source of Variance	**Degrees of Freedom**	**Mean Squares**	**Variance Estimate**	**F-Value**	***p*-Value**
Subjects (S)	18	0.970	0.054		
Between Drives (D)	3	0.297	0.099	10.298	**<0.0001**
Interaction S x D	54	0.519	0.010		
Between Sections of Route (R)	6	0.392	0.065	13.129	**<0.0001**
Interaction S x R	108	0.538	0.005		
Interaction D x R	18	0.073	0.004	1.374	0.1420
Interaction S x D x R	324	0.961	0.003		

Table 3.8 indicates that there were two statistically significant main effects. Steering performance differed for the four drives ($p<0.0001$) and for the section of the route ($p<0.0001$). Both effects are illustrated in the graph presented in Figure 3.3.

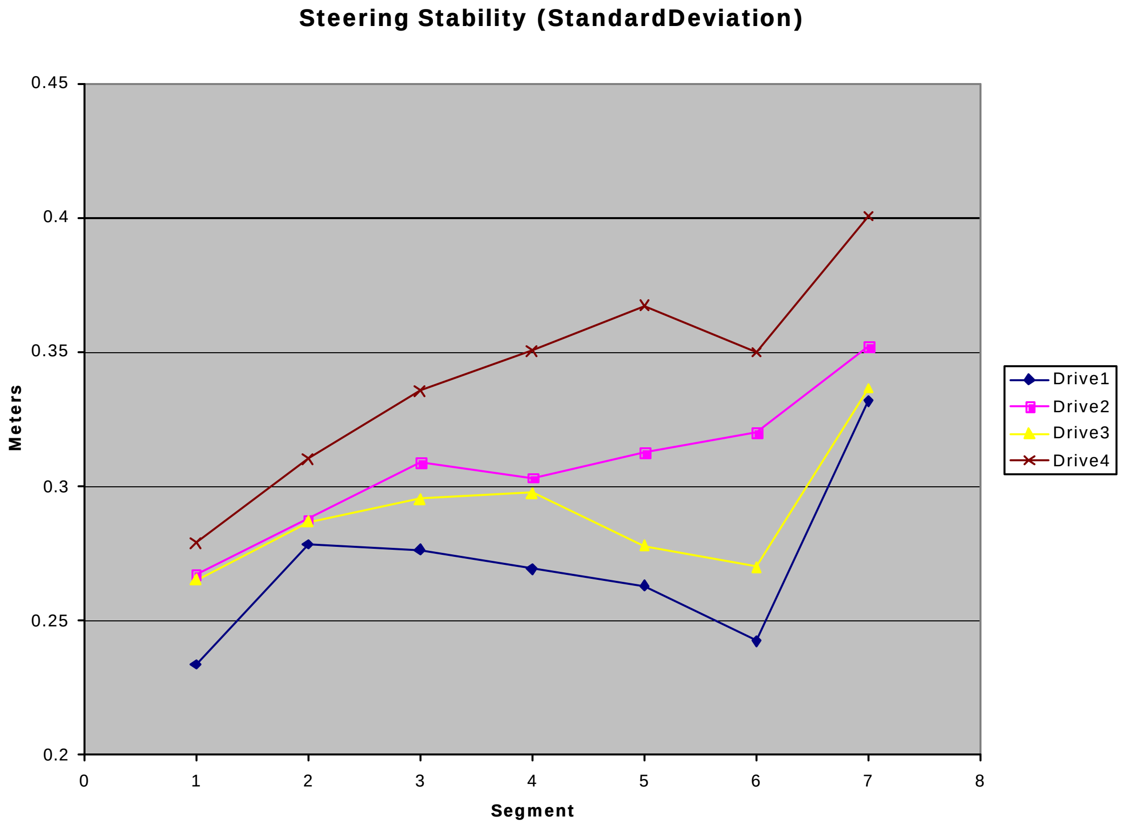

Figure 3.3: Variability in steering performance in the seven sections of the test route for each of the four drives

Figure 3.3 shows that, for all four drives on average, the participants had the least variability in steering during the first segment of the drive and the most variability during the seventh segment. [This finding is discussed further in a report currently in preparation for the larger fatigue project. This report will also give details of the other performance measures collected in this experiment.]

Figure 3.3 shows that steering performance was poorest for the drive at night (at 2:00 a.m. or 3:00 a.m.) and the drive in the afternoon (at 2:00 p.m. or 3:00 p.m.), better for the evening drive (at 8:00 p.m. or 9:00 p.m.), and best of all for the morning drive (at 8:00 a.m. or 9:00 a.m.). This finding is as expected from our knowledge of circadian rhythms. For example, with reference to truck drivers, Prokop and Prokop (1955) found that the frequency with which 500 truck drivers reported falling asleep at the wheel was highest during two periods—(1) at the circadian low point between 2:00 a.m. and 6:00 a.m.; and (2) at the secondary circadian low point after lunch between 2:00 p.m. and 4:00 p.m.

The steering variability data clearly reveal that the drivers were impaired as a result of sleep deprivation. The finding that rumble strips, despite driver fatigue, consistently produced similar, more controlled, stopping patterns (in comparison to the intersection without rumble strips) speaks to their effectiveness with sleep deprived drivers.

CHAPTER 4
CONCLUSION AND FUTURE PLANS

4.1 Conclusion

A series of three studies is being conducted by the authors in order to investigate various aspects of rumble strips. The first study (Harder *et al*, 2001) was conducted in a driving simulator with participants who were *attentive* drivers. The study showed that rumble strips affected the *braking pattern* of the driver. Subsequently, in a field study unrelated to this series, Fitzpatrick *et al* (2002) reported that there was a less gradual deceleration *after* rumble strips had been installed at intersections than *before* their installation.

In this, the second of our series of three rumble strip studies, the objective was to investigate the effect of in-lane rumble strips on the stopping performance of *sleep-deprived* drivers. Twenty commercial motor vehicle drivers were tested over a twenty-hour period, during which they were continuously kept awake. During this period they drove in a driving simulator for approximately one hour on four occasions—in the morning, the afternoon, the evening and at night.

The key finding of the study was that, despite the fatigue of the drivers, the *braking pattern* of the drivers was affected by the presence of the rumble strips. From the appearance of the first set of rumble strips, 218 meters (715.2 ft) from the intersection up to the point at which the drivers stopped, the mean speed of drivers approaching the intersection *with* the rumble strips was statistically significantly slower than the mean speed for drivers approaching the intersection *without* the rumble strips.

The finding that rumble strips consistently affected the stopping pattern of the drivers on their four drives is made more evident in that there was no statistically significant difference in mean speeds on the two intersection approaches before the drivers reached the point on the approach where the rumble strips occurred. The *presence* of rumble strips caused the drivers to brake to a greater extent earlier in the approach.

The findings are interesting particularly because the experimental participants were commercial vehicle operators. Commercial vehicle operators are trained to perform at a higher level than other drivers and are thus typically better drivers. Thus the finding that rumble strips had a consistent and pronounced effect on their stopping behavior on each of the four drives is striking. It is anticipated that rumble strips would similarly foster safer stopping behavior for regular (non-professional) sleep-deprived drivers.

Interestingly, though no apparent effects of sleep deprivation were found to affect the braking patterns of the drivers as they approached the stop-controlled intersections, sleep deprivation was shown to affect the steering performance of the drivers—they exhibited considerably more variability in steering on the fourth drive which occurred at night (at 2:00 a.m. or 3:00 a.m.) than they had in their first drive in the morning (at 8:00 a.m. or

9:00 a.m.). This finding provides clear evidence that fatigue impaired driving performance.

4.2 Future Rumble Strip Research

In the first two studies of this series we investigated the effect of rumble strips on stopping behavior at simulated rural controlled intersections—in the first study with attentive drivers and in the second with drivers who were sleep-deprived. In both studies, we found that the presence of rumble strips affected the braking pattern of the drivers as they approached the intersections. They brake earlier and to a greater extent when they are further away from the intersection, when rumble strips are installed, than they do if there are no rumble strips.

Nevertheless, these results should not be interpreted as definitive with regard to the role of rumble strips. The results of the current study indicate that, despite driver fatigue, rumble strips consistently produce slower, more controlled, stopping behavior. The fact remains, however, that no drivers in this study ran the stop sign at either the intersection *with* rumble strips or the intersection *without* rumble strips.

The third study, which has just begun, will help to complete our understanding of the way in which rumble strips affect the stopping behavior of drivers. Stopping behavior will be investigated at real-world intersections at various locations in Minnesota. We will compare the stopping behavior that occurs at similar intersections, *with* and *without* rumble strips. We will investigate a number of intersections with varying features (e.g., sightlines and topography).

In summary, the first two studies are important contributions to the existing body of knowledge regarding the role that rumble strips play on stopping behavior at stop-controlled intersections. Upon completion of the third study we will have a more complete understanding of their effectiveness. Considered together the three studies should provide a sound basis on which to offer recommendations for the use of rumble strips.

REFERENCES

Bloomfield, J. R. and Carroll, S. A. (1996). New Measures of Driving Performance. In: Robertson, S.A. (Editor) *Contemporary Ergonomics 1996*. London: Taylor and Francis 335-340.

Corkle, J., Marti, M., and Montebello, D. (2001). Synthesis on the Effectiveness of Rumble Strips. Report Number 2002-07. Minnesota Local Road Research Board.

Dinges, D.F. and Powell, J.W. (1985). Microcomputer Analysis of Performance on a Portable Simple Visual RT Task during Sustained Operations. *Behavior Research Methods, Instruments, & Computers*, **17**, 652-655.

Fitzpatrick, K., Brewer, M.A., and Parnham, A.H. (2002). Left-Turn and Rumble Strip Treatments for Rural Intersections. Project Summary Report 0-4278-S. Texas Transportation Institute, Texas A&M University System.

Harder, K. A., Bloomfield, J.R., and Chihak, B. J. (2001). The Effective of In-Lane Rumble Strips on the Stopping Behavior of Attentive Drivers. Final Technical Report Number 2002-11 submitted to Minnesota Local Road Research Board, October 2001.

MUTCD (2001). *Manual on Uniform Traffic Devices (Millennium Edition—Revised December 2001)*. U.S. Department of Transportation, Washington DC: Federal Highway Administration.

Prokop, O. and Prokop, L. (1955). Ermüdung und Einschalafen am Steuer [Fatigue and Falling Asleep in Driving]. *Deutsche Zeitschrift für Gerichtliche Medizin*, **44**, 343-355. [Cited by Grandjean, E. *Fitting the task to the man: a textbook of occupational ergonomics*. London: Taylor and Francis.]

Wilkinson, R.T. and Houghton, D. (1982). Field Test of Arousal: A Portable Reaction Timer with Data Storage. *Human Factors*, **24**, 487-493.

Appendix A
Screening Questions

Appendix A: Screening Questions

The following set of questions was used to screen all those who were interested in the study.

1. Personal Details
Name____________________
Telephone number________________

2. Job Related
When do you usually start work?____________________
When do you usually finish working for the day?____________________
Do you work irregular shifts? ____________________
Are you a third shift worker (11:00 PM to 7:00 AM)?____________________

3. Driving experience
Do you have a current driving license? ____________________
How long have you had a driving license? ____________________
Are you between the ages of 25 and 60? ____________________

4. Eyesight
Do you have glasses or contact lenses? ____________________
If you do have glasses or contact lenses, when did you last have your eyes tested?____________________
If you do not have glasses or contact lenses, has a doctor or other health professional told you that you should have your eyes tested? ____________________

5. (For female subject) Pregnancy
Are you pregnant?____________________
When was your last menstrual period?____________________
[Screener will inform subject that] If selected for this study, you will be required to take a Pregnancy Test at the Preliminary Screening Visit and at the beginning of the Main Study. And only if the pregnancy tests are negative, will you be able continue on in the Main Study. If the Pregnancy Test is positive, you will *not* be allowed to continue on in the Main Study____________________
Do you have a young child who you are still breast feeding?____________________

6. Headaches and Motion Sickness

Do you get migraines or severe tension headaches?____________________
Do you have motion sickness in automobiles?____________________
Do you have motion sickness in airplanes?____________________
Do you get sick on any amusement park rides?____________________
Do you feel queasy at IMAX presentations?____________________

7. Medical

Do you have a sleep disorder?—e.g., such as sleep apnea, insomnia or narcolepsy.____________________
When was your last complete physical examination at the doctor's?____________________
In that visit, did you have blood tests? ____________________
In that visit, did you have a urine test?____________________
Were any diagnostic tests ordered?____________________
If you did what were the results of those tests?____________________
Did the doctor prescribe any medicines as a result of that visit?____________________
Did you get a prescription after the physical?____________________
When did you last see your doctor?____________________
Did you get a prescription on that visit?____________________
What prescription medications are you taking at the moment?____________________
How many times a day do you take prescription medications?____________________
At what time(s) of day do you take prescription medications?____________________
What over the counter medicines are you taking at the moment?____________________
Do you take anything for headaches?____________________
Do you take anything for allergies?____________________
Do you take any vitamins?____________________
Do you take any herbal supplements?____________________

8. Alcohol Consumption

How often do you drink alcohol?

—Almost every day.
—Five or six days a week.
—Three or four days a week.
—Once or twice a week.
—Once or twice a month.
—Once or twice a year.

How many days did you drink last week?

—0.
—1.
—2.
—3.
—4.
—5.
—6.
—7.

When you drink, how many drinks per day do you have?

—0.
—1.
—2.
—3.
—4.
—5.
—6.
—7.
—8 or more.

If you are selected for this experiment, would you be willing to consume alcohol up to 0.04 before your last drive in the driving Simulator?___________________
Also, if you are selected for this experiment, would you be willing to <u>not</u> drink any alcohol the day before the experiment?___________________

<u>9. Caffeine Consumption</u>
How many cups of coffee do you drink a day___________________
How many caffeinated beverages like Coke, Pepsi, Mountain Dew, Jolt, Surge, etc. do you drink a day?___________________

<u>10. Tobacco Consumption</u>
Currently, do you use any form of tobacco.___________________
Have you ever used any form of tobacco?___________________
If yes, when did you last use it?___________________

<u>11. Length of Main Study</u>
The Main Study will last for as long as 30 hours.
Are you willing to stay for as long as 30 hours?___________________
After your last drive in the simulator, for safety reasons, you must stay at the Sleep Facility for approximately ten hours.___________________
Are you willing to stay in the Sleep Facility for as long as eleven hours?__________________

Appendix B
Sleep Diary

Participant #_______

Fatigue Study: Sleep Diary

Principal Investigator—John Bloomfield
Co-Principal Investigator—Kathleen Harder

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Sleep Diary—Day 1:________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **<u>ONE</u>** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 2:________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **ONE** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 3:_________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **<u>ONE</u>** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 4:________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **ONE** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 5:_________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **<u>ONE</u>** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 6:_________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **<u>ONE</u>** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 7:________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **<u>ONE</u>** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 8:________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **ONE** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______

Sleep Diary—Day 9:________________

1. Please give details of the **main** sleep period that you had today in the table below.

	Main sleep period
Time you went to bed:	
Time you woke up:	
Sleep Duration:	
Number of times you woke up during the sleep period:	

2. Please tick **ONE** of the following boxes to indicate whether the **main** sleep period that you had today was:

A. About normal for you _____

B. Shorter than normal _____

C. Longer than normal _____

3. Please choose a number between one and seven that best reflects your sleep during the **main** sleep period that you had today.

Ease of falling asleep

Very Hard 1 2 3 4 5 6 7 Very easy

Ease of getting up

Very Hard 1 2 3 4 5 6 7 Very easy

Depth of sleep

Very Shallow 1 2 3 4 5 6 7 Very Deep

4. Did you take any naps today? Yes___ No___

5. If you did take any naps, how long did you sleep during them ______