DEVELOPMENT AND EVALUATION OF AN UNIQUE CENTERLINE RUMBLE STRIP PATTERN TO IMPROVE DRIVER COMPREHENSION

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ABSTRACT

To address problems with cross-over-centerline crashes on two- and four-lane undivided roadways, states have installed rumble strips on roadway's centerline as a countermeasure. Most of the states are using a typical shoulder rumble strip pattern and design on the centerline, creating an identical rumble strip pattern on each side of the travel lane. Based on previously conducted research, it appears that this "sharing" may be a violation of drivers expectancy as 27 percent of drivers encountering the centerline rumble strip by chance corrected left instead of right in low vision conditions. It was hypothesized that if the shoulder and centerline patterns were different and provided different messages to the driver, then drivers would be more likely to respond correctly to the signal.

A multi-phase experimental procedure was developed to explore this hypothesis. This paper presents the results of this analysis. Several unique rumble strip patterns were designed and evaluated under different driving conditions. Consideration was given to a number of variables including sound production, vibration, and departure angles. The results show that a unique centerline rumble strip pattern, different from the continuous shoulder rumble strip pattern, leads to better driver comprehension and higher percentages of correct responses under low vision conditions. Consideration should be given to implementing different rumble strip patterns when used on centerline or left shoulder locations.

INTRODUCTION

Rumble strips are a series of longitudinal bumps or indentations installed along a roadway used to aid drivers in their lateral positioning. Based on their configuration, rumble strips alter the flat surface that drivers are familiar with, providing a distinct sound and vibrational pattern to the driver when encountered. There are two basic strip configurations, those that are installed on the surface (raised), and those that are an integral part of the pavement (milled). Strips may be installed at the time of roadway construction (i.e., rolled) or after construction (i.e., milled or raised).

In view of the success of shoulder rumble strips in reducing the number of run-off-road crashes, many states (20 in early 2000 (1)) began using shoulder rumble strip patterns and spacing on the centerline of two- and four-lane roadways, in both rural and urban applications, and on some divided freeways medians as a countermeasure to cross-over-centerline crashes (COCC). Transportation officials believed that centerline rumble strips (CRS) may aid in alerting drowsy or inattentive drivers to their lateral position on the roadway, so that corrective actions could be taken.

Although there are different construction methods used for installing rumble strips, centerline rumble strips have typically been milled. Using this construction method, some states have slightly modified their shoulder rumble strips (SRS) pattern on the centerline in an attempt to present a unique or discernable sound/vibration to the driver. Unfortunately, in many instances, shoulder and centerline rumble strips provide the same audio and tactile message, potentially confusing the driver when they are encountered unexpectedly.

Typical dimensions and depths of rumbles strips currently used are provided in Tables 1 and 2. It is clear that the general specifications being used today are quite similar between centerline and shoulder applications.

TABLE 1 Summary of State's SRS Specification.

Type	Length, (Direction of Travel), cm/inches	Median Width, (perpendicular to traffic), cm/inches	Depth, Radius, cm/inches	Center to Center Spacing, cm/inches
Milled	18.0/7.1	39.9/15.7	1.27,30/0.5, 12	29.9/11.8
Rolled	5.1/2.0	70.1/27.6	2.54/1.0	20.1/7.9
Formed	5.8/2.3	75.7/29.8	2.54/1.0	11.4/4.5

TABLE 2 Partial Listing of State's CRS Milled Specifications (2).

State	*Length cm/inches*	*Width cm/inches*	*Depth cm/inches*	*Center to Center Spacing cm/inches*	*Location*	*Comments*
Arizona	16.5/6.5	30.5/12 20.3/8 12.7/5	1.3/0.5	Continuous 30.5/12	All Zones	Markings installed over strips Narrow to reduce res noise Narrow to reduce res noise
California	16.5/6.5	40.6/16	1.3/0.5	Continuous 70/24	No Pass Only	Used with thermo and reflect.
Connecticut	16.5/6.5	40.6/16	1.3/0.5	Continuous 30.5/12	No Pass Only	Markings installed over strips
Colorado	16.5/6.5	30.5/12	1.3/0.5	Continuous 30.5/12	All Zones	Markings installed over strips
Massachusetts	16.5/6.5	45.7/18	1.3/0.5	Continuous 30.5/12	No Pass Only	Markings installed over strips
Oregon	17.8/7.0	40.6/16	1.6/0.63	Continuous 30.5/12	No Pass Only	Used with 4 ft median
Pennsylvania	16.5/6.5	76.2/30 40.6/16 40.6/16 45.7/18 25.4/10 30.5/12	1.3/0.5	Alternating 61/24 & Alternating 122/48	No Pass Only	Across CL - 12 ft lanes Outside CL - 12 ft lanes Between CL - 12 ft lanes Across CL - 11 ft lanes Outside CL - 11 ft lanes Between CL - 11 ft lanes
Washington	16.5/6.5	40.6/16 40.6/16	1.3/0.5	Continuous 30.5/12 Continuous 70/24		Markings installed over strips Makings installed over strips
Alberta, Canada	16.5/6.5	30.5/12	1.3/0.5	Continuous 30.5/12	All Zones	Markings installed over strips

Hypothesizing that an alternate pattern may improve driver comprehension pertaining to rumble strip encounters, several states have experimented with altered SRS patterns for centerline applications (FIGURE 1). Researchers at Kansas State University evaluated the different noise and vibration levels associated with the combinations presented and found that the patterns that produced the largest value of noise, in decibels, was the pattern that had the strips spaced continuously 30.5cm (12 inches) on center. The greatest vibration was found to be from the pattern that alternated the strips, two separated by a distance of 30.5cm (12 inches), the gap between the double strips at 61 cm (24 inches) (2). These findings were considered as alternative rumble strip patterns were considered.

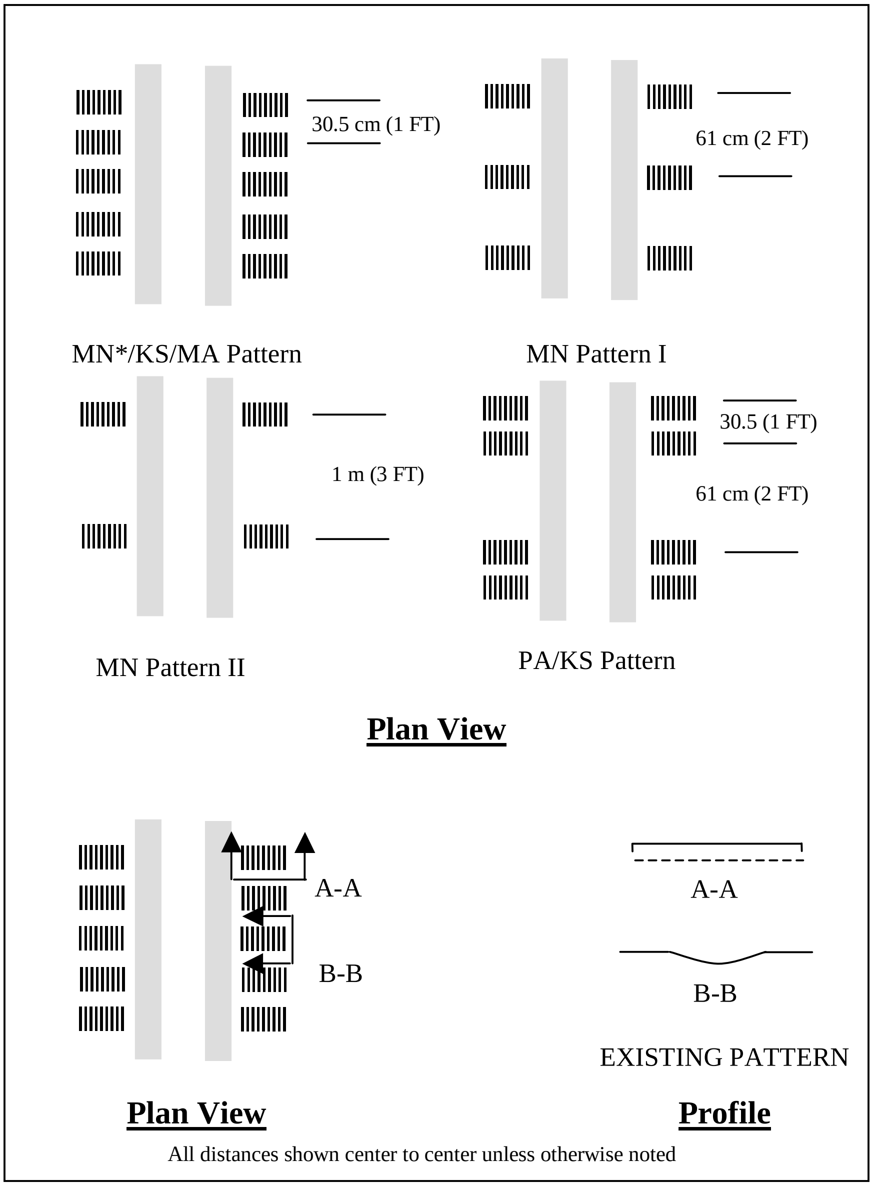


FIGURE 1 Potential Rumble Strips Test Patterns and Profiles (1,2,3).

PROBLEM STATEMENT

Considering the similarities between the CRS and pattern and the SRS and pattern, if a CRS were encountered, drivers may not know what side of the vehicle the noise and vibration were coming from, and without a visual cue, they many not correct properly. The process should be much more automatic than relying on visual cues in combination with the audible and tactile clues. This research focused on identifying multi-modal differences in the existing patterns and then using that information to create a unique centerline rumble strip pattern. The creation was facilitated through the initial findings as well as from the integration of a number of factors including vehicle wheelbase, and roadway departure angle.

FIELD WORK

The primary objective of the first phase of this research was to quantify the audible and haptic differences between continuous shoulder and centerline rumble strips. Outside of the visual queues, sound and vibration were identified as the primary factors in rumble strip communication with the driver. To address these differences, a two phase approach was defined – phase 1 involved identifying the audible and haptic differences. In the first phase, sound and vibrational signatures were collected from the field. Two different technologies were used to record each, an advanced sound recording device and an accelerometer. These devices were used to capture sound and vibration waveforms from actual incursions. Phase 2 used the phase 1 findings to create a unique centerline pattern.

The fieldwork focused on using milled rumble strip's sounds and vibrations, due to their widespread use and acceptance. A passenger car was selected as the experimental vehicle. Data were collected with the windows closed and the radio turned off. A constant vehicle speed of 96 km/hr (60 mph) was used throughout the evaluation.

Sound Signature

To record sounds from inside the vehicle's cabin, a passenger car was temporarily equipped with a Knowles Electronics Manikin for Acoustics Research (KEMAR). The manikin's microphones, located at the end of each ear canal, are located at an average ear elevation and location to ensure that the sound level and direction is similar to that experienced by drivers in the real world.

The manikin was placed in the passenger seat when the pattern signatures were recorded. Because the manikin was seated in the passenger seat, the incursions were reversed – the shoulder rumble strip incursion took place on the driver’s side of the vehicle, and vice versa. This reverse approach ensured that the sounds and vibration incursions in the evaluation environment were broadcast from the proper vehicle side.

KEMAR was connected to a sound recording rig that electronically recorded the sounds. As the vehicle was driven along the roadway, a recording was made of the sounds in the vehicle's cabin. The test vehicle was driven down a roadway and two series of recordings were made, a baseline/background sound and an incursion sound. Once the background data were established, the vehicle was driven over the rumble strips at the pre-defined speed, with the rumble strips on the passenger side of the vehicle. Again, the acoustical signature was recorded. This reversal ensured that the acoustical sound signature realistically represented a future centerline incursion (driving the vehicle over the strips from the proper travel direction may not be realistically represented in the laboratory). This was used as the "incursion" sound.

Vibration Signature

A three-axis accelerometer was used to objectively quantify the incursions vibrational differences, for both the shoulder and centerline rumble strips. The accelerometer allowed researchers to measure acceleration along the longitudinal, lateral, and gravitational axes. It was hypothesized that the changes in acceleration along the axes for the two different incursion locations would be readily discernable.

Realizing that certain in-vehicle hardware may dampen the signal that is transmitted from the tires to the driver, two locations were used for data collection, namely, the steering column and the clutch pedal (FIGURE 2). Both locations were anticipated to provide the optimum signal strength as well as information regarding the relative position of different items in the vehicle's cabin and the vibration intensity associated with each, regardless of incursion location. The clutch pedal was used in place of the accelerator to ensure driver safety - the research team wanted to avoid any unwanted interaction between the driver's foot and the accelerometer cable.

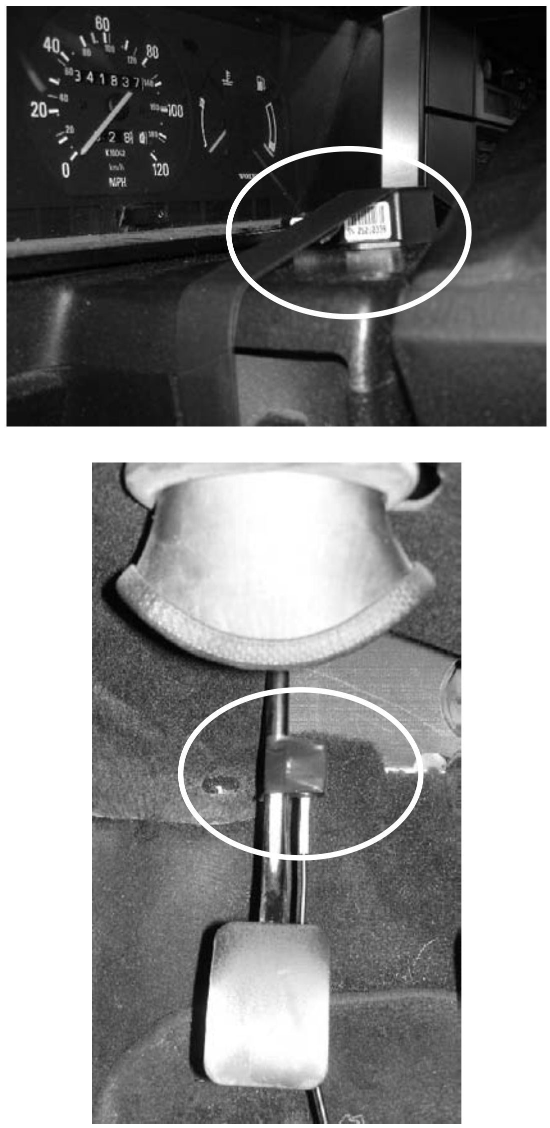
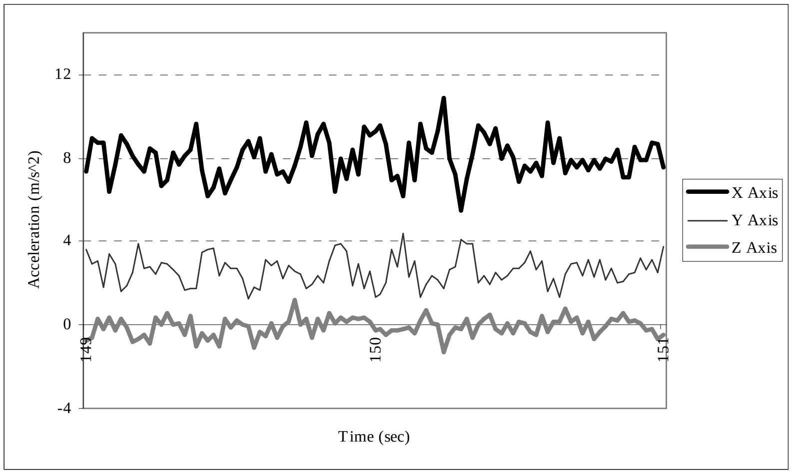


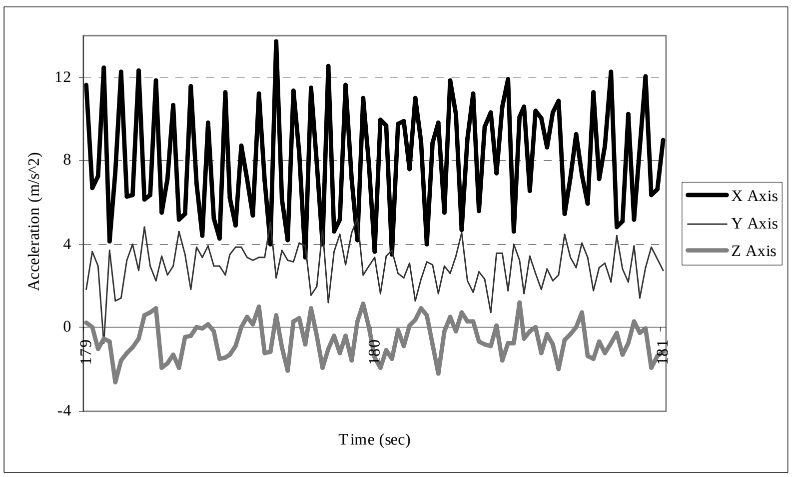
FIGURE 2 Accelerometer Mounted on Steering Column (top) and Clutch Pedal (bottom).

While the vehicle was driven down the roadway, three distinct acceleration signatures were recorded, a background signature, a shoulder signature and a centerline signature. The background signature was recorded when the vehicle was properly located (laterally) in the lane. A shoulder signature was recorded when the vehicle was driven over the shoulder rumble strips. Similarly, a centerline signature was recorded when the vehicle was driven over the centerline rumble strips.

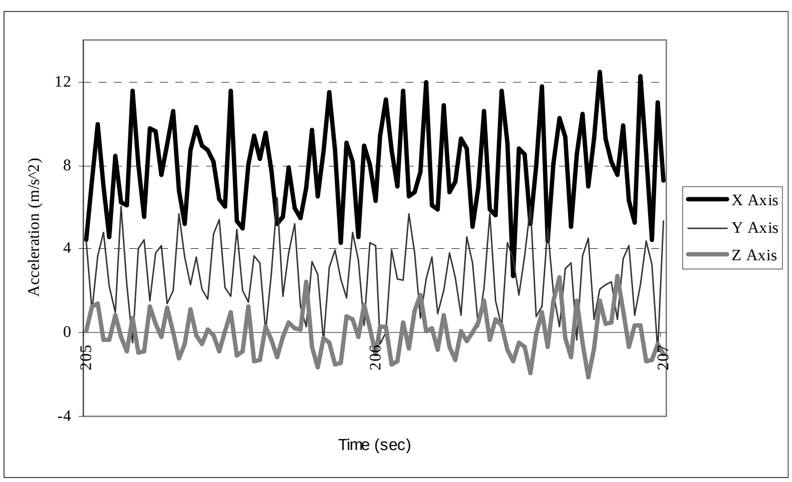
To record data, the accelerometer was connected to a laptop computer in the vehicle. Software recorded the accelerometer's change in acceleration every 0.02 seconds along each of the three axes. An acceleration profile was recorded for each incursion and each mounting location. FIGURE 3 shows the steering column acceleration, the clutch pedal is left out for brevity. Each figure shows the acceleration along an individual axis. Along the ordinate is the acceleration, in m/s^2 and along the abscissa is the time scale, in seconds. In the figure, the x axis is perpendicular to the travel way; therefore the acceleration value is close to the earth's gravitational pull of 9.8 m/s^2 (32.3 ft/s^2) (close is mentioned here because the vibration of the vehicle did cause the accelerometer to record a gravitational force closer to 8.0 m/s^2). The y and z axes are in the lateral and longitudinal direction, respectively.



Background Acceleration



Shoulder Incursion



Centerline Incursion

FIGURE 3 Steering Column Acceleration.

Sound and Vibration Results

The sound wave profiles recorded for each of the incursion types are shown in FIGURE 4. Realizing that the waves are over modulated, a "clean" figure was also provided that shows individual incursions. The wave files were chosen randomly from the field-recorded sound file. In each figure there are two profiles presented, the upper profile is the left channel, or left ear track, and the bottom profile is the right channel (ear) track. The time, in seconds, is listed along the upper abscissa, while the sound level, in decibels is shown along the ordinate.

One of the limitations of the sound software was the inability to export specific wave values, therefore the differences were noted through inspection. Based on observations of the data presented (FIGURE 4) it appears that the waveforms from both the shoulder incursion and centerline incursion have similar characteristics. The overall characteristics for each wave are similar - the amplitudes of the waves are similar; therefore, the differences do not appear to be large enough to make it perceptible to an average driver.

Unlike the sound software that did not allow for the exporting of unique values, the waveforms from the accelerometer data were generated by individual points; therefore, the values could be used for further analysis. Using the data from the field, a statistical analysis was performed (TABLE 3).

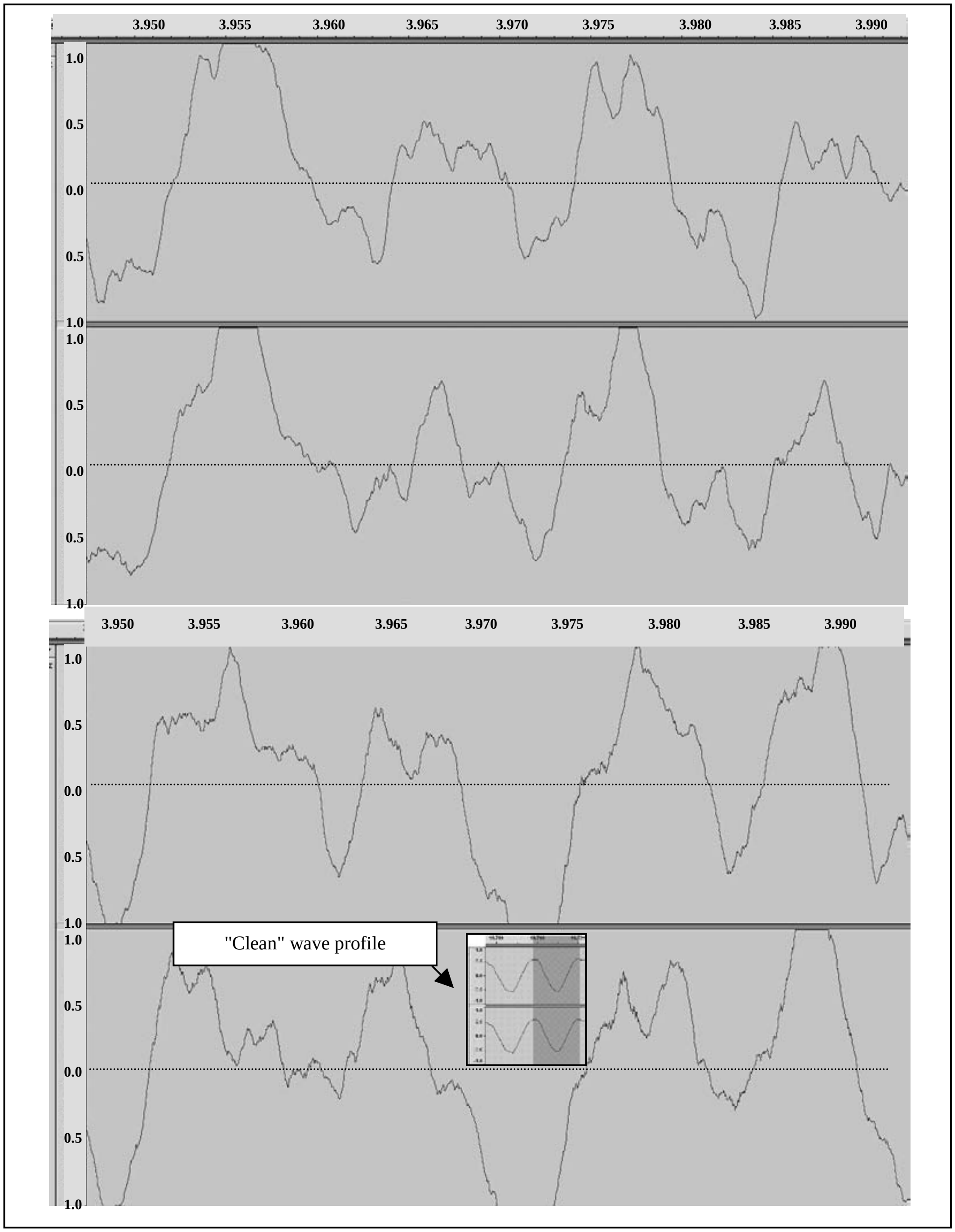
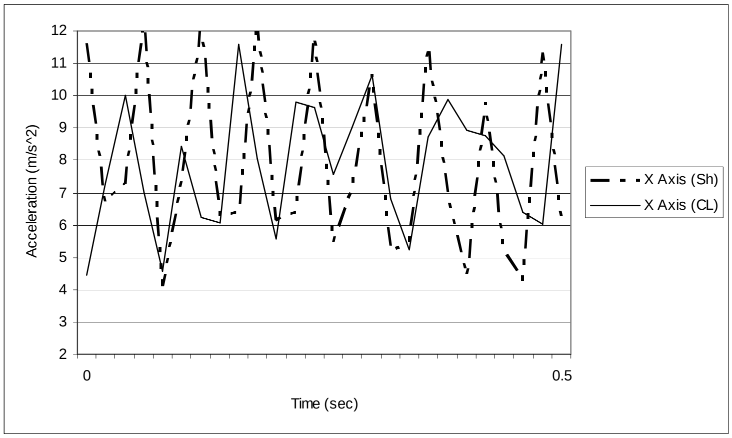


FIGURE 4 Sound Wave Profiles - Centerline (Top) - Shoulder (Bottom).

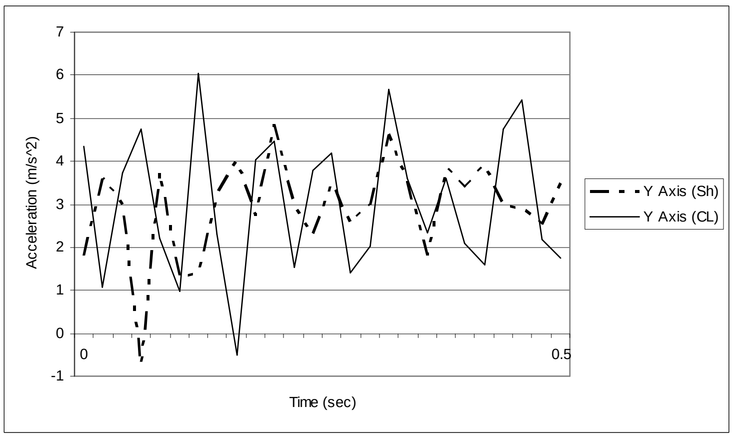
TABLE 3 Steering Column Acceleration - Statistical Data.

	Background		
	X Axis	***Y Axis***	***Z Axis***
Average Acceleration (m/s²)	8.02	2.61	-0.10
Variance	0.94	0.48	0.19
Standard Deviation	0.97	0.70	0.44
	Shoulder		
	X Axis	***Y Axis***	***Z Axis***
Average Acceleration (m/s²)	8.10	2.99	-0.54
Variance	7.56	1.01	0.75
Standard Deviation	2.75	1.01	0.86
	Centerline		
	X Axis	***Y Axis***	***Z Axis***
Average Acceleration (m/s²)	7.94	2.75	-0.04
Variance	4.71	3.01	1.03
Standard Deviation	2.17	1.73	1.01

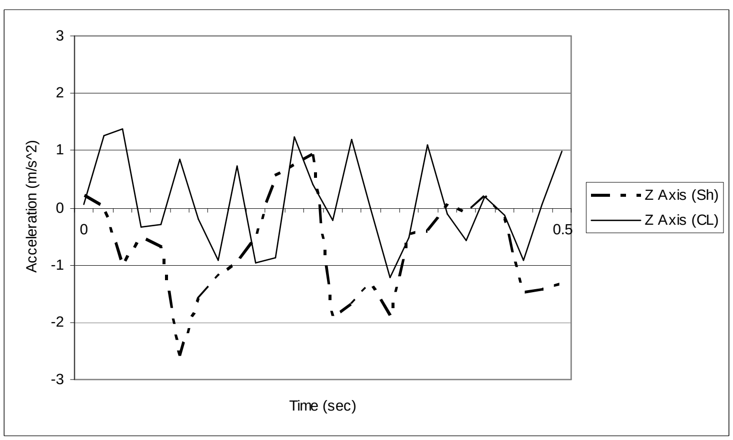
Comparing the average acceleration along each axis results in a difference that is less than 1 m/s^2 when considering the shoulder vs. centerline incursion; however, there is a greater difference (>1) in the difference for the standard deviation when the background signal is compared with either the shoulder or centerline. Considering the difference in standard deviation, it appears that there is a perceptible difference between the background and either incursion, yet the difference between the shoulder and centerline is much less perceptible. Additional figures (FIGURE 5) were generated to compare the acceleration between the different incursion types. The double-dashed bold line in FIGURE 5 represents shoulder incursions, while the narrower solid line represents centerline incursions. As can be observed, changes in acceleration along the x axis are much more uniform than the centerline incursion; however, both are similar in amplitude. Changes in acceleration along the y-axis appear to be opposite from the x-axis acceleration, where there appears to be no discernable pattern for either incursion on the y axis. Furthermore, both are similar in amplitude. Similar to the y axis, there appears to be no discernable pattern for either incursion on the z axis. As with the other incursions, the accelerations along the z axis are similar in amplitude.



X Axis Acceleration - Shoulder/Centerline



Y Axis Acceleration - Shoulder/Centerline



Z Axis Acceleration - Shoulder/Centerline.

FIGURE 5 Shoulder and Centerline Incursion Acceleration.

An analysis of variance (ANOVA) was also performed on the accelerometer data from each incursion (shoulder, centerline) for each axis (x, y, z) shown in FIGURE 5. There were no statistically significant differences for the steering mounting position and only statistically significant difference for the clutch mounting ($p=0.039$) along the x axis. Based on these findings, it appears that the driver has to rely on the difference in waveforms to discern the incursion location, which, as demonstrated through the use of the figures, may be a challenging task.

Since the sound signature and vibration signature appeared to refute the assertions that the signal strength varies depending on which side of the vehicle the incursion occurs on, a methodology was developed to create a readily discernable pattern. That approach is outlined in the next section.

UNIQUE CENTERLINE RUMBLE STRIP PATTERNS

The field-recorded sounds were downloaded into a software program for viewing and manipulation. The software used, Audacity (4) allows the user to view the sound waveform as shown in FIGURE 4 (clean). Similar to other software programs, Audacity also allows the user to "cut, copy, and paste" different sections of the waveform to generate the desired sound. Through this cut, copy, and paste process, the field-recorded sounds were used to create unique patterns by combining segments of the background sounds with incursion sound, into three unique rumble strip patterns.

For instance, one pattern that was considered for evaluation was a 4 - 16 - 4 pattern. The four 4 refers to the number of strips in a given length, or in this case, 4 strips spaced 30.5cm (1 foot) on center. Similarly, the second number, or 16, refers to the spacing between the end of the last four foot section and the start of the next four foot section (FIGURE 6) in US Customary Units. In theory, to generate this pattern, an incursion cycle was inserted four times, and then a background length of 16 feet, followed by a four foot pattern.

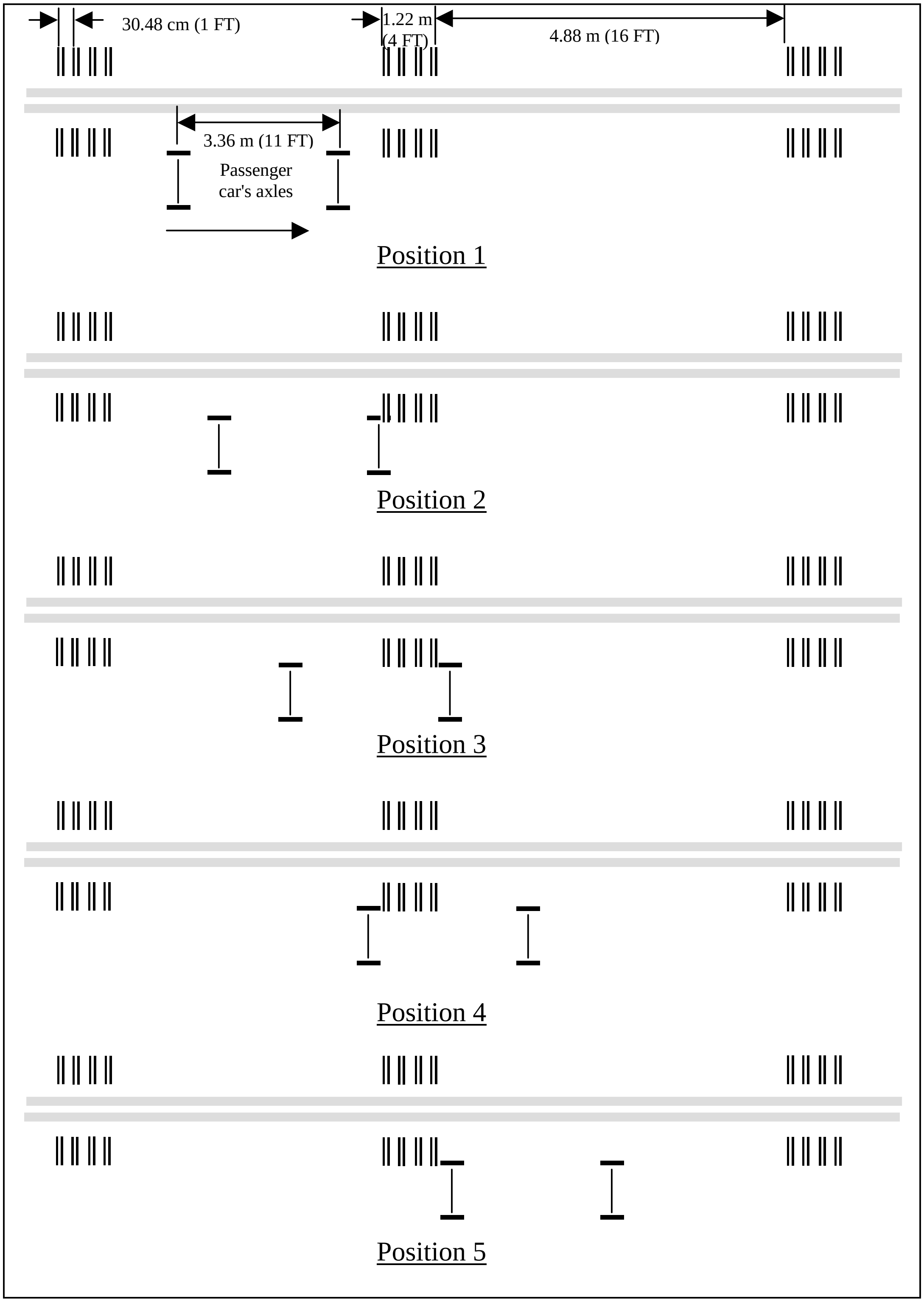


FIGURE 6 Rumble Strip Incursion - Two Axle Vehicle Pattern Creation.

Although the physical spacing is 4-16-4, the pattern was modified to reflect the sound that would be expected if a strip pattern like this were encountered. Using a sound incursion pattern of four feet, then a background sound of sixteen feet, followed by an incursion pattern of four feet would be suitable if a single axle vehicle encountered the strips. Since all vehicles on the roadway have at least two axles, the sound pattern had to be modified to reflect an actual incursion. Although the distance between the rumble strip groups is sixteen feet, the sounds from the incursions are encountered more frequently than the physical spacing. FIGURE 6 demonstrates the frequency in which the strips are encountered by a passenger vehicle (wheelbase = 3.36 m (11 ft)).

In FIGURE 6 at position 1, the vehicle's axles are not in contact with any of the strips. The front axle encounters the strip while the rear axle is still traveling on the ungrooved pavement in position 2. The front axle has rolled off of the rumble strip pattern, and there is still 1.53 meters (five feet) of ungrooved pavement remaining before the rear axle encounters the pattern in position 3. In position 4, the rear axle is just coming into contact with the strips. The rear axle, in position 5, has just rolled off of the strips, while the front axle is five feet away from the next incursion. Therefore, although the pattern spacing is 4-16-4, the sounds are generated in the following sequence:

incursion (1.22 m (4 ft)) - background (2.13m (7 ft)) - incursion (1.22m (4ft)) -
background (1.53 m (5ft)) - repeat

Following this same logic, and using roadway departure information outlined in the next section, a number of other patterns were considered for evaluation.

Roadway Departure Angle

The initial evaluation assumed a 96 km/hr (60 mph) vehicle travel speed and a roadway departure angle of one degree. Researchers considered a range of travel speeds and departure angles, but decided to initially focus on a highway speed and a very shallow departure angle, consistent with a gentle drift common with drowsy driving. Given these characteristics, it takes a passenger vehicle (AASHTO design vehicle) 1.216 seconds to travel from the near edge of a 40.6 cm (16 inch wide) (transverse to direction of travel) rumble strip in their lane to the far edge of a rumble strip in the opposite lane. If a continuous pattern is used, a driver encounters 107 rumble strips. Although the continuous pattern is not an ideal option for use on the centerline (violates driver expectancy), it is a benchmark for pattern creation. The number of incursions during the 1.216 seconds it takes to drive over the 40.6 cm (16 in) wide strips was used as a benchmark for other pattern generation. A number of other patterns were considered that would provide, as close as possible, a maximum number of strips that when encountered would generate a signal that was readily discernable to the driver.

Five additional patterns were generated (TABLE 4). Each pattern listed in TABLE 4 assumes a 17.8 cm (seven inch) long (direction of travel), a 1.27 cm (half inch) deep radial (30.5 cm/12 inch radius) groove, that is 40.6 cm (16 in wide) (transverse to travel). The values for the number of strips encountered assumed the roadway departure angle as shown.

TABLE 4 Number of Rumble Strips Encountered Based on Pattern and Departure Angle.

Pattern	Roadway Departure Angle (degrees)			Average Number of Incursions	Ranking based on number of strip incursions
	1	2	3		
	Number of strips encountered	Number of strips encountered	Number of strips encountered		
Continuous 30.5cm (1foot) center to center spacing	107	50	33	63.33	1
Every other 60.96 cm (2 feet) center-to-center spacing	53	25	17	31.67	2
Every third 1 m (3 feet) center-to-center spacing	36	17	10	21	5
1.22-4.86-1.22 (m) 4-16-4 (ft)	24	12	8	14.67	6
3.05-4.86-3.05 (m) 10-16-10	42	21	10	24.33	4
6.11-6.11-6.11 (m) 20-20-20	45	22	16	27.67	3

The second pattern (every other (61 cm (two feet) center-to-center)) in TABLE 4 is based on every other strip being removed from the continuous pattern, resulting in a 61 cm (two foot) center-to-center spacing. When this pattern is used, a departing vehicle encounters half of the continuous pattern, or approximately 53 strips. The third pattern in TABLE 4 is based on the removal of every second and third strip from the continuous pattern resulting in a strip spacing of one meter (three feet), center-to-center. Changing the strip spacing to one meter (three feet) results in even fewer strips being encountered (36 strips).

The remaining patterns in TABLE 4 were not only based on creating a pattern that had a number of incursions that was close to the benchmark, but also on a design vehicle. The remaining three patterns were generated considering a vehicle's wheelbase as outlined in the previous section. Ensuring that the front and rear tire were not occupying strips at the same time, (i.e., the front axle is beginning to roll over the strips as the rear axle leaves the strips and vice versa) potentially creating a signal that resembles a continuous pattern, other pattern spacings, with a distance between "groups" of strips that was greater than 3.36 meters (11 feet), were chosen. This methodology also provides a larger gap that may suffice cyclists wishing to cut across the roadway. Four patterns were generated, those listed in the last four rows of TABLE 4. Although there are only three listed in the table, there were many others that were considered that were ruled out based on the signal resemblance to the continuous pattern.

Although the every other spacing has the highest number of incursions second to the continuous pattern it was not considered – after a number of drivers were beta tested it was discovered that the sound closely resembled a continuous pattern. The two unique centerline patterns (3.05-4.86-3.05 (10-16-10)) and (6.11-6.11-6.11 (20-20-20)) were tested in a static evaluation. It was anticipated through the static evaluation that the number of unique patterns would be narrowed from two to one for use in the following dynamic environment. The following section describes the evaluation and presents findings.

STATIC EVALUATION

The static evaluation was a computer-based evaluation that required drivers to correct when they were going to run-off-the road to the right toward a shoulder of questionable integrity, or cross over the centerline where vehicles may be present. The static evaluation was given to 100 drivers, 56 percent were male, 44 percent female - 13 percent were in the under 23 years category, 56 percent were in between the age of 22 and 45, while 31 percent were over the age of 45.

The evaluation consisted of a series of images that were automatically presented to the driver on a computer monitor. The images presented to drivers comprise two consecutive images, taken from the driver's perspective on a two lane, undivided rural roadway. The first image presented had the driver properly located (laterally) in the lane. The second image placed the left edge of the vehicle on the centerline or the right edge of the vehicle on the edge line.

There were two basic rubrics for the images, namely a "clear" group and a "foggy" group (FIGURE 7). In the clear group, the roadway, pavement markings, and current lateral position was easily recognizable by the driver. In the foggy group, the first image was slightly overexposed, providing a foggy or hazy view – pavement markings were barely visible. The second image in the foggy group was completely overexposed, in which the driver could not discern their lateral position by the visual cues alone. This condition simulated conditions in which the roadway, and pavement markings may not be visible to the driver for a brief period of time (e.g., intense fog, white-out conditions in snow). Each set of images was automatically and randomly presented to each driver on a computer monitor. Speakers were positioned next to the monitor, and a subwoofer near the driver's feet to broadcast the sound and vibration of a rumble strip incursion. Driver's responses and response times were archived by the program for future analysis.

Prior to beginning the survey, each driver was presented with a short slide show of instructions during which the driver was instructed that they were about to see a number of images, all in groups of two. In the first image, their vehicle was properly located (laterally) in the lane. When the second image appeared the driver would be "drifting" toward the shoulder or centerline. To correct their drifting they were instructed to press a button on the keyboard. Sound accompanied some of the second images, namely field recorded rumble strip incursion - original (shoulder) and altered (centerline intermittent pattern I and ii). Both of the intermittent patterns were being considered for centerline implementation.

There were two portions in the evaluation, one uninformed and one informed, always presented in that order. The driver took the uninformed portion without any additional instruction other than what to do in the evaluation. After "driving" through the uninformed portion, a brief slide show was presented on the computer. During this information intermission, drivers were presented with information related to traffic control devices including rumble strips. Information presented the "double use" of the continuous pattern – on the shoulder and centerline, while the intermittent pattern would only be used on the centerline.

FIGURE 7 Static Evaluation - Sequential Images (Left (position 1), Right (position 2)) - Foggy Conditions (top) - Clear Conditions, Centerline Incursion (Middle) - Clear Conditions, Shoulder Incursion (Bottom).

In the instructions, the drivers were informed that they should press one of three keys, a key to correct left, one to correct right, or if the were unsure they could press the space bar. After reviewing the recorded data, a fourth response was noted, namely none.

The correct responses were obvious - in the clear conditions, correct to avoid potential incursions, while in the foggy conditions the task was more challenging. In the foggy conditions, a response of "I am not sure" is the correct response for both situations when no sound is presented and when the continuous pattern is presented, given the ambiguity of the pattern.

RESULTS

The percentage of correct responses is shown in FIGURE 8 for both the uninformed and informed portion of the evaluation, in clear and foggy conditions. Also shown is the 95 percent confidence interval for each group of responses. In foggy conditions, drivers responded correctly when presented with a continuous pattern 52 percent of the time, 29 percent post information. With regard to the intermittent pattern in the fog, drivers responded correctly 24 percent of the time for intermittent pattern i and 20 percent for intermittent pattern ii. In the post information intermission, drivers responded correctly 78 percent of the time for intermittent pattern i and 78 percent for intermittent pattern ii.

For all scenarios, drivers in the clear condition scenarios responded correctly on average 85 percent (low = 82, high = 87) of the time before the informational intermission and on average 91 percent (low = 89, high = 94) of the time after the informational intermission. When presented with the foggy condition, drivers responded correctly on average 40 percent (low = 21, high = 62) of the time prior to the informational intermission and on average 66 percent (low = 29, high = 79). The outlier in the post information intermission scenario is the continuous pattern in the foggy condition in which the drivers were only correct 29 percent of the time. As can be observed in FIGURE 8, there was a significant improvement in driver’s reaction to the intermittent patterns once they were made aware of them.

A chi square analysis was performed on the aggregate data, comparing the uninformed data with the informed data. A two (rows) by two (column) matrix was used. The values for the columns reflected the possible answers (correct, incorrect) while the rows reflected the conditions, before and after. In the clear conditions, the intermittent i pattern (i) was significant (p=0.001) when the uninformed portion of the evaluation with compared to the informed portion. In the foggy conditions, each group was significant (no sound, continuous, intermittent (i) and intermittent (ii)) (p=0.001), when the uninformed portion of the evaluation was compared to the informed portion of the evaluation.

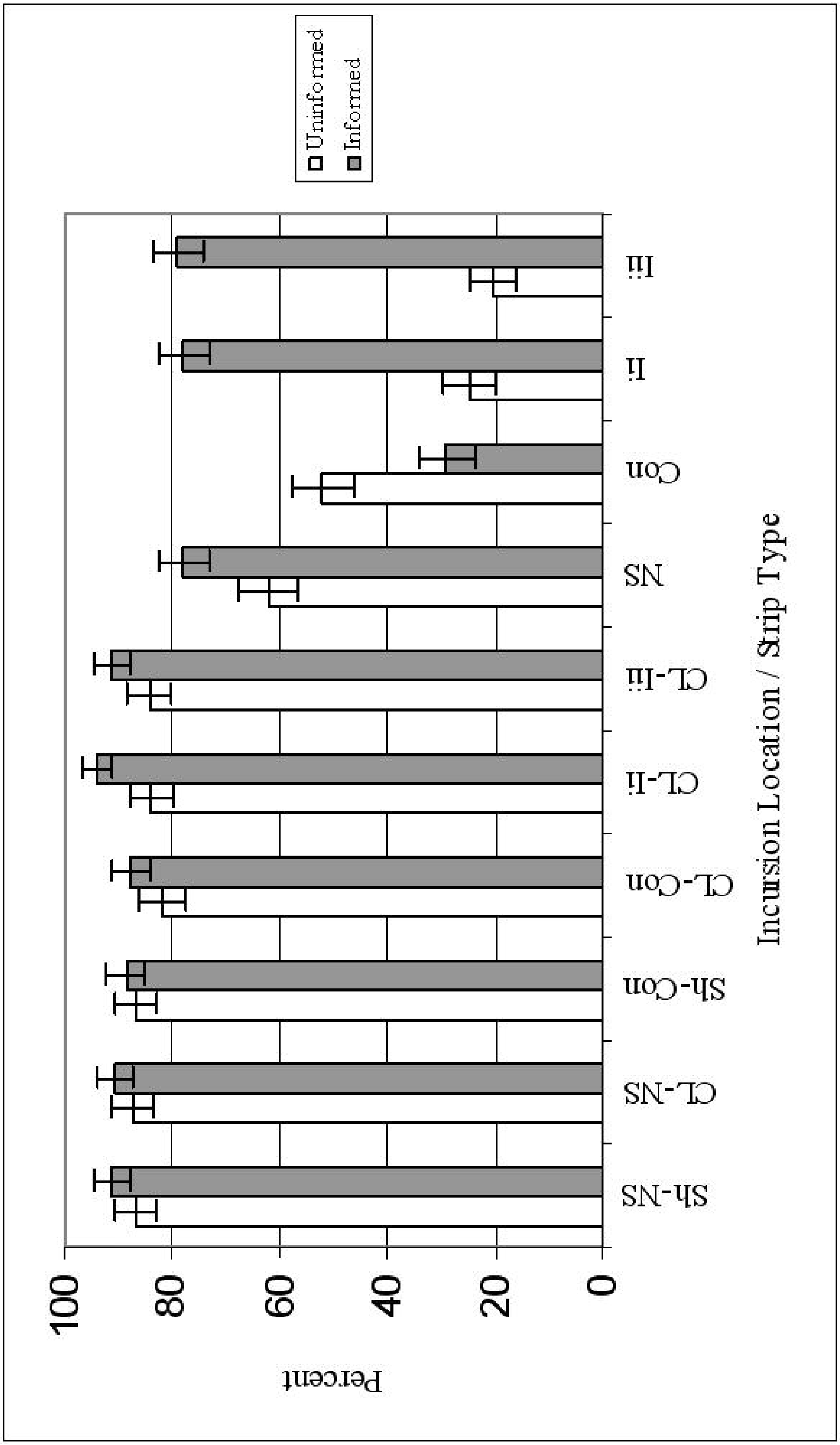


FIGURE 8 Correct Responses - Static Evaluation

CONCLUSIONS

Through this process it appears that there is no evidence to support anecdotal information regarding a rumble strip's signal strength depending on incursion type - the audible and haptic waveforms appear to be so similar that without the visual cue, the difference may be imperceptible to the driver. Considering this, it is even more critical that the research presented herein with regard to the creation of a unique centerline rumble strip pattern be evaluated further. The methodical process addressed and integrated various aspects of design, including audible and haptic signatures as well as the vehicle's wheelbase and roadway departure angle.

Based on the findings in the static evaluation it appears that the intermittent pattern has promise. There was an increase in the number of correct responses after the drivers were informed as to what the sounds were in accompanying some of the images.

The original driving simulator study found that when a continuous rumble strip pattern was encountered on the centerline 27 percent of the drivers corrected left. In the static evaluation, 24 percent of the drivers corrected left when a continuous pattern was encountered in foggy conditions during the uninformed portion.

After the informational intermission, drivers were aware of the possibility of the continuous pattern being present on the shoulder or centerline. Once drivers were aware of the possible dual location of the continuous pattern, the correct left responses or fail critical (correcting left when on the centerline) responses increased. It appears not only do these findings support the original findings from the driving simulator, their magnitude, at least in the uninformed portion of the evaluation, closely mirrors the original findings.

Once drivers were aware that the continuous pattern may exist on either side of the roadway, their "I am not sure which way to correct" responses increased when presented with the continuous pattern. Although this was the correct answer in the evaluation, from an operation perspective it was not the desired choice - drivers should be able to react properly when presented with specific cues. With the intermittent patterns, drivers were able to correctly discern their lateral location, properly correct, and avoid consequences. It is envisioned that a response similar to this would occur in the field, once drivers became aware of the different types of rumble strips. It appears that an intermittent pattern provides the unambiguous cues that transportation professionals and human factors researchers rely on.

The next and perhaps the most critical step in the research will be performed in the Human Performance Laboratory's Driving Simulator at the University of Massachusetts-Amherst. The main objective in the dynamic evaluation will be to identify if having a unique pattern on the centerline was discernable by drivers in a simulated environment. A following step will include field evaluations of the most effective patterns identified in the laboratory experiments. It is anticipated that results will closely mirror those from the static evaluation.

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