Evaluation of Football Shaped Rumble Strips Versus Rectangular Rumble Strips

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Shoulder and centerline rumble strips have become predominantly used safety measures along American highways in almost all states and in Canadian provinces. Milled shoulder rumble strips are cut indentations along the shoulder of a highway to warn drivers with an audible and tactile alert if they start drifting off the road. Centerline rumble strips are similar, but are placed between lanes, usually on undivided two-way, two-lane highways, to warn drivers who may start drifting into oncoming traffic. Researchers at Kansas State University (KSU) have conducted research on a new football-shaped highway rumble strip designed by an independent firm in Kansas. Test strips were installed along a Kansas highway, and the KSU research team conducted several tests to evaluate the new football shaped rumble strip versus the rectangular rumble strip. The comparison consisted of water and debris collection, interior sound and vibration production, and the opinions of bicyclists.Based on the literature review, the limited tests performed, and the surveys conducted, it can be concluded that no significant difference was found between the two types of rumble strips.

INTRODUCTION

Highway Shoulder Rumble Strips (SRS) have proven to be an effective measure in reducing run-off-the-road (ROR) crashes on urban and rural highways. ROR crashes may be reduced by as much as 20% to 50% when rumble strips are installed (Torbic et al. 2003). Many states continue to research the effectiveness of installed SRS by using before and after studies. Milled-in rumble strips in Michigan reduced ROR crashes by 40% (Morena 2003). Pennsylvania and New York found a reduction of ROR crashes of 60% and 80% percent, respectively, after the installation of milled-in SRS (Brin 2001; Morena 2003). Annino (2003) found a 40% decrease in fatality accidents related to ROR in Connecticut. Finally, the Virginia Department of Transportation (DOT) reported a 42% reduction in fatal ROR crashes and an overall 32% reduction in ROR due to the installation of milled-in SRS (Chen et al. 2003). The Virginia DOT also reported a benefit/cost ratio of +45, meaning every dollar invested returns $45 in benefits (Chen et al. 2003). According to the Federal Highway Administration (FHWA), studies indicate benefit/cost ratios between 60:1 and 128:1 from the use of milled-in SRS as a road treatment for reducing ROR accidents (Neumann 2002).

Since August 1999, researchers at Kansas State University have been conducting research on rumble strips and their use on highways in the United States (U.S.). The research showed that states use different sizes and patterns of rumble strips. A literature review of current designs, effects, and issues is included in the next section of this paper.

A private company from Towanda, Kansas has designed a new type of rumble strip for shoulders and centerlines. The design is oval in shape, resembling a football. The company claims that the uniquely rounded design allows wind and rain to clean the self-draining indentations while maintaining the audible and tactile warning signals. Also, the company claims that the gradual increase in depth of the indentation is more bicycle and motorcycle friendly (Dustrol 2003). The overall objective of this project is to compare the effectiveness of the new football shaped rumble strips to the conventional rectangular rumble strips.

LITERATURE REVIEW

According to the FHWA (2001), there are four basic rumble strip designs or types: milled-in, rolled, formed (corrugated), and raised. The most widely used milled-in strips are cut into the pavement surface using a grinding head. The most common dimension for milled shoulder rumble strips (SRS) is ½-inch deep, seven inches wide (parallel to the travel lane), and 16 inches long (perpendicular to the travel lane) (FHWA 2001). These dimensions are a basis for many states to use when designing milled-in rumble strips for highway shoulder use.

In some states, sections of rumble strips are used intermittently with short sections without rumble strips; other states install the rumble strips continuously. In most states, the rumble strips are installed with some space between the right edge of pavement and the edge of the rumble strips. This offset distance varies by state, from zero (no offset) to 12 inches are common.

The distance between individual rumble strips is measured from center to center of adjacent rumble strips. Patterns vary, but 12-inch spacing is most common.

Shoulder Rumble Strip Designs by State

The Virginia DOT used the dimensions previously described when conducting research on the effects of continuous SRS on highway safety (Chen et al. 2003). Connecticut, Iowa, and Maryland also use the FHWA dimensions for milled-in SRS cut continuously 12 inches center-to-center offset 12 inches from the edge-of-travel line (Annino 2003).

Some states use variations of the FHWA dimensions due to research and bicyclist issues discussed later in this paper. A recent study produced for the Missouri DOT (MoDOT) suggests a 7/16-inch deep, five-inch wide (parallel to the travel lane), and 12-inch long (perpendicular to the travel lane) milled-in SRS as optimal for all non-interstate highways with shoulder widths of five to six feet (Spring 2003). The SRS on non-interstate highways with shoulder widths of five to six feet use an intermittent pattern, alternating 60 feet of rumble strips with a 12-foot gap between adjacent 60-foot sections, offset zero inches from the edge-of-travel line. Spring (2003) also suggests that the FHWA design (FHWA 2001) should still be used for all interstate highway SRS applications and for all non-interstate highways with shoulders exceeding six feet. All Missouri non-interstate highways use an intermittent pattern alternating 60 feet of rumble strips with a 12-foot gap between adjacent 60-foot sections. Interstate highway shoulder rumble strips in Missouri are cut continuously, 12 inches center-to-center with an offset of six inches from the right edge of the roadway pavement, i.e., travel lane. All non-interstate highways with shoulders exceeding six feet use the intermittent pattern, alternating 60 feet of rumble strips with a 12-foot gap between adjacent 60-foot sections, and are offset six inches from the edge-of-travel lane. The MoDOT proposal coincides with the study completed at the Midwest Research Institute in Kansas City, Missouri (Torbic et al. 2003). Torbic and his associates found that using the 7/16-inch by five inch by 12 inch design is more "bicycle-friendly."

The North Dakota DOT has similar guidelines to that of Spring's report. Sixteen-inch SRS are used on interstates and are cut continuously at 12 inches center-to-center and offset 12 inches from the edge-of-travel line. The 12-inch SRS are used on all multilane divided highways, multilane undivided highways, and two-lane highways with shoulders between four and six feet (Birst 2002). The SRS on multilane divided highways are cut continuously 12 inches center-to-center offset 12 inches from the edge-of-travel line on the left side of the road. The right side of multilane divided highways uses an intermittent pattern, alternating 40 feet of rumble strips with a 10-foot gap between adjacent 40-foot sections, offset 12 inches from the edge-of-travel line. Multilane undivided highways use the intermittent pattern on both sides of the highway. Two-lane highways use the continuous pattern cut 12 inches center-to-center offset 12 inches from the edge-of-travel line.

The Canadian province of British Columbia also uses five-inch wide (parallel to the travel lane) and 12-inch long (perpendicular to the travel lane) rumble strips. However, the SRS are only cut to a maximum depth of 3/8-inch. For shoulders greater than or equal to five feet, the strips are cut continuously 12 inches center-to-center with an offset of four inches from the edge-of-travel line. For shoulders between two and a half and five feet, SRS are cut continuously 12 inches center-to-center with an offset of zero inches from the edge-of-travel line (Coulter 2003).

Michigan uses three types of SRS: milled-in, rolled-in, and corrugated (Morena 2003). No dimensions for design are available, but the Michigan Department of Transportation installs SRS continuously with either a 12- or 24-inch offset from the edge-of-travel line.

No regulations or guidelines state the pattern and placement from the edge-of-travel line. Therefore, states are allowed to determine an optimal pattern on their respective highways.

The Debate over Bicycle Friendly Rumble Strips

Since the first installation of rumble strips, the concern for bicyclist safety along highways with rumble strips has increased. Much bicycling takes place on narrow rural roads with narrow or no paved shoulder, and/or on roads with frequent curves. SRS cannot significantly improve motor vehicle safety on these roads (in the absence of new or wider shoulders), but some believe they dramatically reduce the level of service on those roads for bicycling (Zalph 2005). Researchers from universities, state and federal transportation agencies, and independent firms have looked into better ways to make roads safe for both drivers and bicycle riders. Many bicyclists and bicycle groups have voiced their concerns and opinions, both positive and negative. Currently, there is no federal standard for rumble strips, only recommendations from the FHWA. States have adopted their own policies based upon current research and trends. From this, different designs of rumble strips have been created to become more bicycle friendly on today's highways.

States have listened to the bicycle community and have started to research patterns that can accommodate both drivers and bicyclists. Colorado is one of the leading states in research of bicycle friendly rumble strips. Outcalt (2001) first suggested to the Colorado Department of Transportation that the SRS be milled to 3/8-inch deep instead of 1/2 to 5/8-inch deep. Torbic et al. (2003) determined that the optimal design for bicycle friendly rumble strips is 7/16-inch deep, five inches wide, and 12 inches long. Using SRS with the mentioned dimensions still gives a proper auditory and tactile warning for drivers, and creates enough space for bicyclists (Torbic et al. 2003).

The MoDOT is trying to put more shoulders on routes and work with rumble strips so they are effective in deterring run-off-the-road accidents yet not a problem for bicyclists. The current rumble strip policy provides for the placement of rumble strips on all shoulders that are two feet or wider (however, Missouri's current standards do not provide for the placement of rumble strips on all shoulders less than eight feet wide). The milled rumble strips are four inches outside the edge line, 16 inches long, seven inches wide, and continuous. This policy was added to the Standard Plans July 1, 2004 (Snider 2004). Also, the MoDOT Bicycle and Pedestrian Advisory Committee recently submitted a project to be considered for funding to the American Association of State Highway and Transportation Officials (AASHTO). The project is titled "Rumble Strip Design to Optimize Both Highway and Bicycle Safety" (Giarratano 2004).

In Georgia, The Atlanta Bicycle Campaign made the following recommendations to the Georgia Department of Transportation (GDOT): 1. Reduce depth of rumbles from ½ inch to 3/8 inch as done in Colorado and Pennsylvania, and reduce the width of the rumble gouge from seven to five inches, 2. Reduce the length of the rumble from 16 to 12 inches, 3. Increase the length of gap (currently 28 feet of rumble strips, then a 12 foot gap). All the recommendations have been well accepted and are in the process of being implemented into Georgia's rumble strip policy (Georgia State Pedestrian Advisory Committee 2003).

In Hawaii, rumble strips along the Queen Ka'ahumanu Highway have been temporarily milled down to ¼ inch. This is in response to riders' concerns over the ½-inch deep milled strips along the Kea'au-Pahoa Highway. A professional and a non-professional bike rider tested the ¼ inch strips, and both were satisfied with the modification (Hawaii County Bicycle/Pedestrian Advisory Committee 2004).

West Virginia uses the above design and only places SRS on highways with shoulders greater than or equal to three feet (WVDOT 2003). Washington uses SRS on divided and undivided highways where the shoulder width is greater than four feet. Also, SRS activities must be coordinated with the Washington State Department of Transportation's Bicycle and Pedestrian Advisory Committee (WSDOT 2002).

Bicyclists are still a major factor when designing SRS for use on all highway types.

EXPERIMENTAL ANALYSIS

The private company that designed the football shaped rumble strips claims they offer several benefits over the rectangular rumble strips. The first claim is that the unique rounded design of football rumble strips allows wind and rain to clean the self-draining indentations. The second claim is that the football shaped rumble strips produce the same audible and vibratory warning for drivers crossing over the indentations as the rectangular rumble strips. The final claim is that the football shaped rumble strips are more bicycle friendly.

To test the first claim, an experiment simulated the collection of water and debris in the rumble strip indentations. Both types of rumble strips, football and rectangular, were examined and evaluated based on the time it took for the material in the indentations to be removed. Data on the time of removal, the wind speed, and the number of passing vehicles were collected to evaluate the removal of water and debris from the rumble strips.

To test the second claim, an experiment measured the noise and vibration produced by the rumble strips as felt by a vehicle's driver. A noise dosimeter measured the noise heard by the driver while an accelerometer attached to the steering wheel measured the vibration felt by the driver. Several different vehicles were used, and both types of rumble strips were tested. The strips were compared for any statistical difference between the noise and vibration measurements.

To test the third claim, a survey accurately judged bicyclists' opinions of the two types of rumble strips. A bicyclist group from Wichita, Kansas, compared the football and rectangular shaped rumble strips based on the safety of riding over the strips.

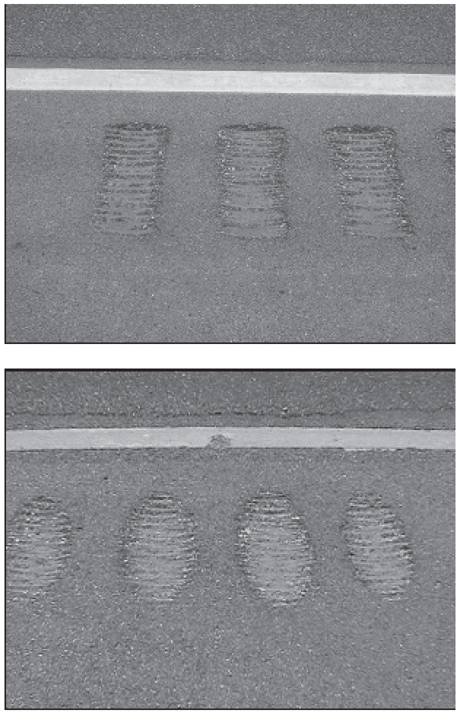
The football shaped rumble strips were first installed in Kansas along the shoulder of Highway K-96 in October 2004. A single football indentation has a depth of approximately 0.5 inch, a width of nine inches, and a length of 16 inches. A single rectangular indentation has a depth of approximately 0.5 inch, a width of seven inches parallel to the line of travel, and a length of 16 inches perpendicular to the line of travel. Each type of rumble strip is set in a pattern of 10 consecutive indentations, then a five-foot gap until the next 10 indentations, and so on. Photographs of each type of rumble strip can be seen in Figure 1. The objective was to determine a positive or negative difference between the two types of rumble strips based on water and debris removal and noise and vibration produced by each type of strip. All tests were conducted along the section of Highway K-96, a multilane divided highway between Wichita and Maize, Kansas. This section of K-96 has a high traffic flow that averages approximately 600 vehicles per hour. The rectangular rumble strips are along the eastbound lanes and the football shaped rumble strips are along the westbound lanes.

Debris and Water Removal Tests

Several tests were conducted using water and sand debris to determine if there is a difference between the two designs of rumble strips, football shaped and rectangular shaped. The tests were conducted over three days and different amounts of time.

For the debris tests, one-quarter cup of Quikrete Multi-Purpose sand was poured into three consecutive divots of each rumble strip design. This simulated road debris collecting in the rumble

Figure 1: Rectangular Rumble Strips (top) versus Football Rumble Strips (bottom)



strips from traffic, wind, tire particulates, and dust. The rumble strips were then videotaped for 30 minutes. Both types could not be tested simultaneously, so the rectangular rumble strips were tested first, then the football shaped rumble strips. The number of vehicles passing by was tallied. The maximum and average wind speed for the 30-minute period was measured using a Kestrel 1000 pocket wind meter. The setup for the second trial was similar to the first; however, both types of strips were tested at the same time. In the second trial, the strips were tested for 18 hours.

For the water tests, one-quarter cup of water was poured into three consecutive divots of each rumble strip design. This simulated water collecting in the rumble strips from rainy weather and snowmelt in winter weather. For the first trial, the rumble strips were videotaped for 30 minutes. Again, since each type of strip could not be tested simultaneously, the rectangular rumble strips were tested first, then the football shaped rumble strips. The number of vehicles passing by was tallied, and the average and maximum wind speed for the 30-minute period was measured. The setup for the second trial was similar to the first. Both types of strips were tested at the same time. In the second trial, the strips were tested for 18 hours.

Results of Debris and Water Removal Tests

There appears to be no quantifiable difference in the two designs of rumble strips based on the water and debris tests. In data from the first debris trial, hardly a grain of sand appears to be removed from either type of the rumble strips' divots after 30 minutes. In the second debris trial, there is still some sand left in each type's divots after 18 hours (Figures 2 and 3). As with the first debris trial, the first water trial shows no observable removal of water from either rumble strip type after 30 minutes (Figures 4 and 5). However, there is complete removal of water from both types of rumble strips in the data from the second water trial. This suggests that water collecting in either type and standing for long periods is not a problem. From the limited testing and subjective evaluation conducted in these trials, neither type of rumble strips appears to be better or worse than the other in regard to retaining debris or water.

Figure 2: Rectangular Rumble Strips, Debris Test Trial 2 at time = 30 minutes (left) and at time = 18 hours (right)

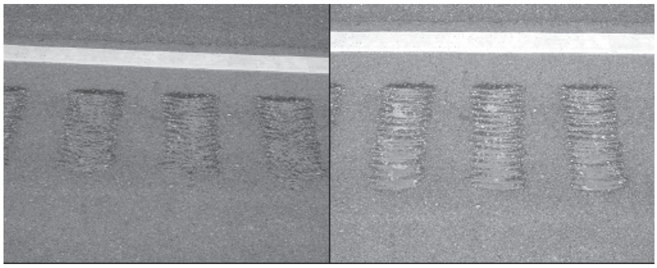


Figure 3: Football Rumble Strips, Debris Test Trial 2 at time = 30 minutes (left) and at time = 18 hours (right)

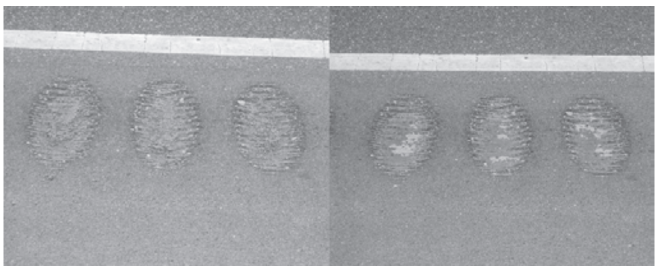


Figure 4: Rectangular Rumble Strips, Water Test Trial 1 at time = 0 min (left) and at time = 30 min (right)

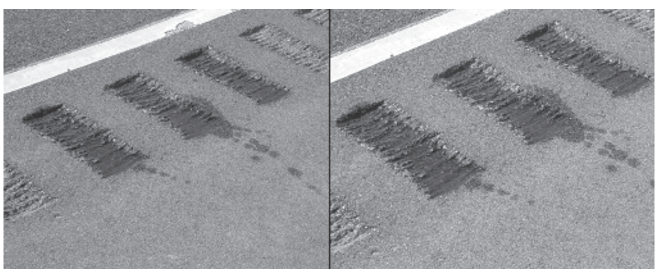
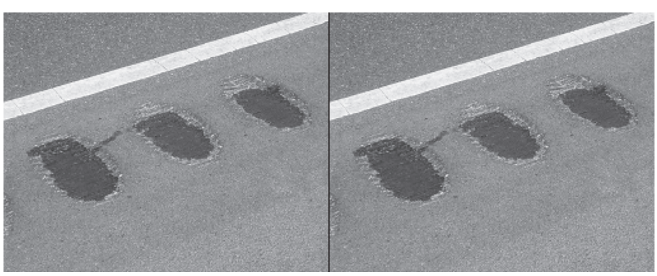


Figure 5: Football Rumble Strips, Water Test Trial 1 at time = 0 min (left) and at time = 30 min (right)



Noise and Vibration Tests

In this data, the noise and vibration produced from vehicle crossover of the rectangular rumble strips is compared to the noise and vibration produced from vehicle crossover of the football shaped rumble strips. The interior noise levels and steering wheel vibration are tested because sound and touch are the two senses that the rumble strips alert when the driver's visual senses become impaired (falling asleep or become distracted) (Brin 2001).

For this experiment, it was determined that several different vehicles would need to be tested to represent the various vehicles that travel along the tested stretch of road, as well as all American highways. Thus, six vehicles were selected and tested. They include a 1996 International 4900 DT466 dump truck, a 1999 Chevrolet 2500 diesel pickup truck, a 2000 Ford Ranger XLT 2WD pickup truck, a 2002 Dodge Caravan, a 1996 Ford Taurus LX, and a 2005 Lexus RX 300 sport utility vehicle. To measure the noise level a driver would hear when traversing a rumble strip, a Quest Technologies Q-300 Noise Dosimeter with an external microphone was attached to the driver's collar. All interior noise including radio, air ventilation, and conversation was kept at a minimum. To measure the vibration level a driver would feel when traversing a rumble strip, a Summit Instruments 35203A Digital Accelerometer was attached to the center of the steering wheel. The accelerometer was directly connected to a laptop computer to collect readings. To accurately operate the noise dosimeter and accelerometer, an assistant went along for each ride. Three tests were completed for each vehicle: a base pass on smooth pavement to determine a normal noise and vibration level for the vehicle, a pass across the rectangular rumble strips, and a pass along the football rumble strips. The driver of each vehicle maintained a speed of approximately 65 miles per hour (mph) for each trial, which is the speed limit on the section tested, as well as on many U.S. highways. The driver maintained the speed while keeping the driver's side tires running along the rumble strips for a distance of 900 feet. Approximately 200 vibration samples were collected for each trial on each vehicle. The accelerometer measured the instantaneous vibration (or g-force) in three axes, x, y, and z. The average noise level in decibels (dBA) was collected and recorded for each trial on each of the six vehicles. An example of one of the tested vehicles traversing the rumble strips can be seen in Figure 6.

Figure 6: One of the Test Vehicles Traversing the Rectangular Rumble Strips

Results and Analysis

Table 1 shows the noise data collected from three runs for each vehicle. As expected, the larger vehicles, i.e. the International and Chevrolet trucks, have a higher base level based on noise produced from their tire contact with the road surface, cab design, exterior wind resistance, and diesel engines. The four other vehicles produced base noise levels similar to each other, with a range of 67.3 dBA to 70.4 dBA. The results from this experiment are comparable to the results of the study conducted by Elefteriadou et al. 2000. No statistical analysis was performed using the dosimeter because only the average noise level was collected and run for each vehicle.

Table 1: Mean Noise Levels Produced by Driving Over Surfaces as Heard by the Driver (dBA)

Vehicle Type	Base Run (dBA)	Rectangular Rumble Strips	Football Rumble Strips
1996 International 4900 DT 466 Dump Truck	85.9	109.0 (23.1)[1]	117.3 (31.4)
1999 Chevrolet 2500 Diesel Pickup Truck	78.5	86.2 (7.7)	86.2 (7.7)
1996 Ford Taurus LX	69.6	78.9 (9.3)	83.3 (13.7)
2000 Ford Ranger XLT 2WD Pickup Truck	70.4	78.2 (7.8)	78.9 (8.5)
2002 Dodge Caravan	67.3	79.6 (12.3)	83.5 (16.2)
2005 Lexus RX 300 SUV	67.4	83.6 (16.2)	83.3 (15.9)

[1] Difference from the Base Run is in parentheses.

The Summit Instruments accelerometer collected vibration along three axes. In order to make a justifiable comparison, the three axis data are combined into a single resultant f(x, y, z) using the equation:

(1) $$f(x,y,z) = \sqrt{x^2 + y^2 + z^2}$$

x – Vibration along the x-axis
y – Vibration along the y-axis
z – Vibration along the z-axis

This equation is used for each sample collected for each trial on each vehicle. Table 2 shows the average f(x, y, z) for the base, football shaped rumble strip, and rectangular shaped rumble strip runs for each tested vehicle.

Table 2: Average f(x, y, z) for Vibration Trials (g)

Vehicle Type	Base Run	Football Rumble Strips	Rectangular Rumble Strips
1996 International 4900 DT 466 Dump Truck	1.027	1.074 (4.5%)[1]	1.084 (5.5%)
1999 Chevrolet 2500 Diesel Truck	1.020	1.036 (1.6%)	1.049 (2.8%)
1996 Ford Taurus LX	1.003	1.089 (8.6%)	1.027 (2.4%)
2000 Ford Ranger XLT 2WD Pickup Truck	1.015	1.053 (3.7%)	1.081 (6.5%)
2002 Dodge Caravan	1.001	1.043 (4.2%)	1.021 (2%)
2005 Lexus RX330 SUV	1.012	1.115 (10.2%)	1.128 (11.5%)

[1] The percent difference from the Base is in parentheses.

In order to accurately compare vibration levels of the rectangular rumble strips to the football shaped rumble strips, two sample t-tests are conducted for each vehicle. For each vehicle, the vibration of the football shaped rumble strip is compared to the rectangular rumble strip. Each test is run at a 95% confidence level. For each test, the null hypothesis is that the means of the resultant for the two runs are equal. The alternate hypothesis is that the means are not equal, showing a difference in the two types of rumble strips. Table 3 shows the test results for the football shaped rumble strips versus the rectangular rumble strips for each vehicle.

Table 3: Two Sample T-test Results for Vibration Levels of Football Rumble Strips versus Rectangular Rumble Strips

Vehicle	Football Mean	Rect. Mean	T-value	p-value
1996 International 4900 DT 466 Dump Truck	1.074	1.084	-0.44	0.658
1999 Chevrolet 2500 Diesel Truck	1.036	1.049	-0.79	0.428
1996 Ford Taurus LX	1.089	1.027	2.38	0.018
2000 Ford Ranger XLT 2WD Pickup Truck	1.053	1.081	-1.47	0.141
2002 Dodge Caravan	1.043	1.021	0.83	0.407
2005 Lexus RX330 SUV	1.115	1.128	-0.63	0.526

Statistical analysis compares the means of the resultants for each vehicle on each type of rumble strip. For five of the vehicles, no statistically significant difference is found between the means of the resultants at a 95% confidence level. The five vehicles are the Chevy diesel truck, the Lexus SUV, the Ford Ranger pickup truck, the International dump truck and the Dodge Caravan. For the Ford Taurus, the mean is significantly different at a 95% confidence level, with the rectangular rumble strip having less vibration.

Noise and Vibration Correlation with Vehicle Tires

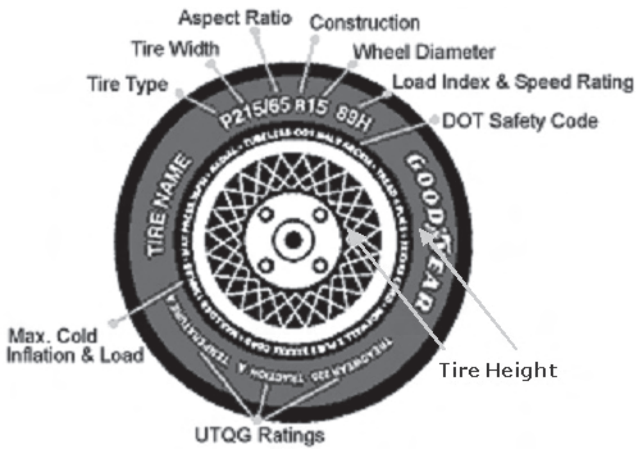
Figure 7 shows how to read the dimensions of a tire from the imprint on the tire. Goodyear (2006) defines the tire width as the distance measured between the broadest points on the tire sidewall, usually given in millimeters (mm). Tire width is the first number in the code, so the width of the tire in Figure 7 is 215 mm. The second number describes the aspect ratio, which is defined as the ratio of the tire's height to the tire's width. The height of the tire in Figure 7 is 65% of the tire's width, or 139.75 mm. All numbers given in millimeters are converted to inches. The tire's height is measured from where the wheel and tire meet to the outer most edge of the tire. By adding the wheel diameter (measured in inches on tire sidewall) to twice the tire's height, we get the tire's diameter.

The values for each vehicle's tire pressure, collected using a standard tire gauge, tire width, and tire diameter are given in Table 4.

Table 4: Tire Pressure, Tire Width and Tire Diameter for the Tested Vehicles

Vehicle	Tire Pressure (psi)	Tire Width (in.)	Tire Diameter (in.)
1996 International 4900 DT466 Dump Truck	100	11.61	40.00
1999 Chevrolet 2500 Diesel Pickup Truck	50	9.65	30.50
1996 Ford Taurus LX	30	8.07	25.50
2000 Ford Ranger XLT 2WD Pickup Truck	34	8.86	27.40
2002 Dodge Caravan	30	8.46	26.80
2005 Lexus RX 300 SUV	31	8.86	28.50

Figure 7: How to Read the Measurements of a Tire



(Goodyear 2006: www.goodyeartires.com/kyt/readingATire)

From this data and the average noise and vibration for each type of vehicle on each type of strip, a simple correlation analysis is performed. Table 5 shows the Pearson correlation values for the average noise and vibration for each type of rumble strip versus tire pressure, tire width, and tire diameter.

Table 5: Correlation Coefficients by Rumble Strip Type versus Tire Pressure, Tire Width, and Tire Diameter

Test	Type of Rumble Strip	Pressure (p-value)	Tire Width (p-value)	Tire Diameter (p-value)
Noise	Rectangular	0.981 (0.001)	0.965 (0.002)	0.990 (0.000)
	Football	0.971 (0.001)	0.920 (0.009)	0.958 (0.003)
Vibration	Rectangular	0.204 (0.699)	0.339 (0.511)	0.335 (0.516)
	Football	-0.06 (0.910)	-0.081 (0.879)	0.001 (0.998)

The correlation coefficients for the average noise collected for each type of rumble strip are all close to one with p-values close to zero. Based on the six vehicles used, there is a significant positive correlation between noise and tire pressure, noise and tire width, and noise and tire diameter for both types of rumble strips. For vibration, there is no correlation with tire pressure, tire width, and tire diameter as the correlation coefficients are close to zero with high p-values for each type of rumble strip. There are several possible reasons for the obtained results. First, the vehicles used all vary in suspension flexibility; therefore, the vibration in each car could drastically vary. Second, the driver of the vehicles had to maintain control of the steering wheel, causing some inertial dampening of the vibration. The noise was controlled, in a sense, from vehicle to vehicle. All possible internal vehicle noise was kept at a minimum. While the test was conducted, the climate control system, radio, any other noise-producing sources were turned off, and the windows were rolled up, to eliminate as much background noise as possible. This gave more accurate noise readings for each vehicle.

Bicyclist Survey

The KSU research team distributed a survey (Table 6) at a monthly meeting of a Wichita based bicyclist group. The purpose of the survey was to gauge the likes and dislikes of football shaped rumble strips as compared to rectangular rumble strips. The bicyclists had all become familiar with the football rumble strips and rectangular rumble strips installed along Highway K-96. Members had either ridden or driven by each type of rumble strip located on the test section of K-96. Twenty three responses were gathered from the attending members.

Table 6: Rumble Strip Questionnaire and Results

1. What do you think of the rectangular shaped rumble strips? • 57 % definitely dislike • 17 % somewhat dislike • 26 % neutral • 0 % somewhat like • 0 % definitely like	**2. What do you think of the football shaped rumble strips?** • 4 % definitely dislike • 13 % somewhat dislike • 13 % neutral • 17 % somewhat like • 53 % definitely like
3. How do the football shaped rumble strips compare to the rectangular rumble strips? • 0 % definitely worse • 0 % somewhat worse • 4 % neutral • 17 % somewhat better • 79 % definitely better	**4. The placement of the football rumble strips gave me plenty of room to ride on the shoulder.**[a] • 0 % definitely disagree • 0 % somewhat disagree • 9 % neutral • 22 % somewhat agree • 69 % definitely agree
5. The size of the football rumble strip did not distract from the safety of my riding. • 0 % definitely disagree • 0 % somewhat disagree • 17 % neutral • 22 % somewhat agree • 61 % definitely agree	**6. The depth of the football rumble strip would not be a problem for me if I rode over them on my bike.** • 0 % definitely disagree • 13 % somewhat disagree • 22 % neutral • 22 % somewhat agree • 43 % definitely agree
7. What is your opinion of rumble strips as pertaining to safety of vehicle drivers from running off the road? • 0 % definitely dislike • 9 % somewhat dislike • 48 % neutral • 17 % somewhat like • 26 % definitely like	**8. What is your overall opinion of rumble strips?** • 30 % definitely dislike • 0 % somewhat dislike • 35 % neutral • 13 % somewhat like • 22 % definitely like

*The distance between the shoulder edge and the rumble strips edge was 49 inches for the football shaped pattern and 45 inches for the rectangular pattern.

Based on questions 1, 2, and 3 of the survey, the bicyclists responded that they do not like the rectangular rumble strips, and they definitely prefer the football shaped rumble strips (Table 6). The bicyclists are also pleased with the placement, size, and depth of the football shaped rumble strips. Based on questions 7 and 8, the bicyclists agree that rumble strips make driving safer. Bicyclists prefer rumble strips that do not cross the entire shoulder and the allowance of at least two to three feet for riding. This is brought out by the additional comments made by the surveyed bicyclists (i.e., *"Rumble strips serve a good purpose to alert drivers who run off the road, but they need to allow room for bicyclists to also ride on the shoulder. They do not need to be the entire width of* *the shoulder.”).* From this limited survey, it can be concluded that the bicyclists prefer the football shaped rumble strips, but they put more emphasis on having enough room on the shoulder to ride, no matter the shape of the rumble strips.

DISCUSSION

As previously stated, there appears to be no difference in the two designs of rumble strips based on the limited water and debris tests. In the first debris trial, no sand appears to be removed from either type of rumble strip divot after 30 minutes. In the second debris trial, there is still some sand left in both designs after 18 hours.

As with the first debris trial, the first water trial shows no observable removal of water from either rumble strip type after 30 minutes. However, there is a complete removal of water from both types of rumble strips in the second water trial. This suggests that water collecting in either design and standing for long periods is not a problem. Subjectively, it is concluded there is no difference between the rumble strip designs in water and debris removal.

To become aware of a sound and be “alerted to the presence of that sound, the sound must typically rise 9 to 10 dBA above the sound of the environment” (Lipscomb 1995). In the case of this experiment, the sound of the environment refers to the base level when normally driving over smooth surface pavement. This study shows the International, Ford Taurus, Dodge Caravan, and Lexus SUV all produce noise levels greater than nine decibels for both types of rumble strips when compared to the base level (Table 1). Therefore, it is possible that drivers of these vehicles would be audibly alerted when crossing over either type of rumble strip. This is beneficial to a large portion of American motorists, including truck drivers who typically operate heavy duty semi-trucks and families who drive sedans/minivans/SUVs. The Chevrolet truck and the Ford Ranger did not reach an increase of at least nine decibels for either rumble strip type, but there was a definite increase over the base level for each vehicle and rumble strip type. More trials for each vehicle would give a better average for each vehicle and may statistically show an increase or decrease in noise levels.

Noise comparisons between each type of rumble strip show noticeable differences in three of the six vehicles tested. The other three vehicles have similar noise levels for each rumble strip type. More trials with each vehicle on each type of rumble strip should be conducted to statistically determine a difference, if any.

Each type of rumble strip shows a considerable vibratory response in each vehicle tested. In the International Dump Truck, the Chevrolet Diesel Truck, the Ford Ranger Pickup Truck, and the Lexus SUV, the rectangular rumble strips produce a higher vibratory level compared to the football rumble strips. Similarly for these four vehicles, the rectangular rumble strips produce a greater percentage difference in vibration from the base value than do the football rumble strips. In the Ford Taurus and the Dodge Caravan, the football rumble strips produce a higher vibratory response and percent difference from the base value compared to the rectangular rumble strips.

According to the statistical tests and based on the vibration levels collected, the rectangular rumble strips give a better vibratory response and have a significant difference over the football rumble strips in the Ford Taurus. The other five vehicles show statistically, no difference. It can be concluded that each type of rumble strip produces a significant tactile response; however, there is not enough evidence to distinguish if one type of rumble strip is superior over the other type of rumble strip for five of the six tested vehicles, or 83% of the vehicles used.

CONCLUSIONS

In the debris and water removal tests, this study subjectively concludes there is no difference between the football and rectangular rumble strips. In the noise and vibration tests, this study concludes there is no difference between the two types of rumble strips. The bicyclists surveyed prefer the football shaped rumble strips but are more concerned with the amount of shoulder room on which to ride.

Therefore, based on the limited number of tests conducted, it is concluded there is no difference between football shaped rumble strips and rectangular shaped rumble strips.

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