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Research

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

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16. Abstract (Limit: 200 words)

This project involved investigating the effect, if any, of rumble strips on stopping behavior at simulated rural-controlled intersections.

Researchers used the wrap-around driver simulator at the University of Minnesota's Human Factors Research Laboratory for the project. Researchers varied the rumble strip type and the number of rumble strips and tested them on two different types of controlled intersections, two-way or four-way, and in the presence and absence of traffic.

Results indicate that none of these manipulations seem to affect the point at which drivers stop at the controlled intersections or the point at which drivers start to slow down at controlled intersections. The research did reveal drivers brake more, earlier, when rumble strips are installed than they do if there are no rumble strips. Although they started to slow down at the same time and finished braking at the same time, there was more use of the brake earlier in the slowing down maneuver in the presence of rumble strips. Results also reveal that drivers brake more and earlier with full coverage rumble strips than they do with wheel track rumble strips.

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

Final Report

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INTRODUCTION

This is the first in what has become a series of three studies that investigate various aspects of 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,” 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” page F-64. All three studies in the series focus on the latter usage.

This study addresses the alerting affect of in-lane rumble strips on the stopping performance of alert drivers. To determine the effect that in-lane rumble strips have on drivers we conducted a driving simulation experiment. In the experiment, we varied the number of rumble strips installed at several otherwise similar thru-STOP intersections. At these intersections there were (1) three in-lane rumble strips, (2) two in-lane rumble strips, or (3) no rumble strips (this provided a control for comparison purposes). We also compared two types of rumble strips: (1) wheel track, or (2) full coverage rumble strips.

The participants were instructed to drive along a simulated two-lane highway “as they normally would.” The stopping behavior of the drivers was recorded at each of the Thru-STOP intersections—both with and without crossing traffic at the intersections.

The results of this study showed that the presence of rumble strips had no effect on the point at which the drivers began to slow down or on the distance away from the intersection at which they actually stopped. However, the presence of the rumble strips did affect the point at which they begin to brake.

This study was conducted with alert drivers. After it was completed, a question remained about the efficacy of rumble strips for less-alert drivers. This question will be explored on the second study in the series. In a driving simulation experiment that is currently scheduled to begin in January 2003, we will investigate the effect of rumble strips on drivers who are impaired in one of two ways: drivers will be either (1) sleep-deprived, or (2) under the influence of alcohol.

In the third study we will consider conditions under which rumble strips might be most effectively employed. For example, we will investigate their effectiveness at sight-limited intersections.

This report presents the variables used in this study, the way in which they were manipulated, the results of the study, and a brief discussion and recommendations section.

METHOD

Participants

There were 32 participants between 18 and 65 years of age (21 males and 11 females). Each had a valid driver's license at the time of the experiment. Participants were reimbursed $10 for their time.

Apparatus

Participants piloted the wrap-around driving simulator (WAS) at the University of Minnesota's Human Factors Research Laboratory. The WAS is a fixed base driving simulator, consisting of a full-body 1990 Acura Integra RS enclosed in a spherical wood and steel dome. The dome measures 12.5 ft (3.81 m) high at its apex and has a 15.5 ft (4.73 m) internal diameter. The car was fitted with sensors to detect accelerator, brake, and steering inputs, providing a real-time interface for the driver. Force feedback was applied to the steering wheel through the steering column with a torque motor. The speedometer was functional, and powered by a small motor that was controlled by the main simulator computer. The car's instrument panel and electrical system were powered by a 12 V, 15 A power supply.

The virtual driving environment was generated with an SGI Onyx computer (Reality Engine 2). The programming was carried out on a MultiGen-Paradigm Vega and SGI Performer APIs. The main simulator computer was a PC, running Linux, which processed all vehicular sensors and controllers. The vehicular hardware interfaced the main simulator computer by means of a National Instruments AT-MIO-16E-10 data card. Information from this computer was transmitted to and from the Onyx via TCP/IP. The Onyx calculated the vehicle dynamics and generated the visual scenario.

Three Proxima 9250+ projectors, operating at a resolution of 640x480 (a resolution that is lower than the capacity of the projectors, but stems from the constraints of the SGI Onyx computer), were used to create the visual scene inside the simulator. The virtual roadway was projected onto a curved seamless 24 ft (7.32 m) x 8 ft (2.44 m) screen positioned in front of the car. Together, the projectors provided a 156-deg forward view. Each projector received a discrete portion of the driving environment from the Onyx.

Engine/road noise was generated by the Onyx and fed through a Dolby Digital® receiver (Yamaha #RX-V795a, Tokyo) to four six-inch loudspeakers inside the car (Infinity #63.1i, Tokyo). The front two loudspeakers were mounted in the locations provided by the car manufacturer for the in-car radio, while the rear speakers were custom-mounted in a traditional rear-deck position. A Cerwin-Vega satellite and subwoofer system, mounted in the trunk of the vehicle, and two Aura bass shakers mounted under the front seats provided low frequency information. A separate stereo receiver (Sony #STR-D365, Tokyo) powered this supplemental system.

When the front wheels of the car touched the virtual rumble strips, an auditory cue was sent through the audio system and the steering wheel vibrated. The frequency of the vibration in the steering wheel was dependant on the speed of the car at the time the wheel touched the rumble strip.

Experimental Design
We were interested in four variables. However, to limit the number of subjects, to stay within budget restraints, and because the current driving simulator precluded us from having simulated cross-traffic at four-way intersections, two 3-way factorial designs were interlocked.

Design 1:
The independent variables (and levels) were the following:
1) Number of rumble strips (zero, two, three) -- within-subjects
2) Presence of traffic (yes, no) -- within subjects
3) Type of rumble strip (wheel track, full coverage) -- between subjects

Design 2:
The independent variables (and levels) were the following:
1) Number of rumble strips (zero, two, three) -- within-subjects
2) Type of Intersection (four-way, two-way) -- within-subjects
3) Type of Rumble Strip (wheel track, full coverage) -- between-subjects

Procedure
Prior to the experiment participants were given a short training session to familiarize them with driving in the simulator.

The experimental environment consisted of a two-lane, bi-directional roadway in a rural environment. The roadway was 25 mi (40.26 km) long with 6 intermittently-occurring 30-deg curves and twelve intersections. (Stopping behavior was recorded at nine of these intersections -- their locations are described in Table 1. The other three intersections were uncontrolled.) Stop Ahead signs were placed alongside the roadway at the U.S. standard distance of 486.75 ft (148.4 m) ahead of the intersection at each of the nine test intersections. Intersections were controlled by either two- or four-way stop signs and had two, three, or no rumble strips. Rumble strips at the intersections with three rumble strips were placed 722.48 ft (220.27 m), 707.48 ft (215.70 m), and 359.14 ft (109.50 m) from the intersection. The rumble strip at the 707.48 ft (215.70) position was absent at the intersections with two rumble strips. In addition, some two-way intersections had uncontrolled cross-traffic. Half of the participants encountered rumble strips that covered the entire width of the lane and the other half of the participants encountered wheel-track rumble strips. The four-way intersection containing no rumble strips and no traffic was the first intersection presented to all participants. The remaining eight experimental conditions were randomly ordered for the participants. The random orders are shown in Table 2.

Following the experimental session, participants completed a short questionnaire regarding their perception of the rumble strips. The experimenter also debriefed them.

Table 1. Location of intersections

Intersection Number	Location in miles (km)
1	2 (3.22)
2	5 (8.05)
3	7 (11.27)
4	8 (12.88)
5	12 (19.32)
6	15 (24.15)
7	18 (28.98)
8	19 (30.60)
9	24 (38.65)

Table 2. Random order of experimental conditions for both rumble strip types (wheel track and full width)

Routes	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6	Trial #7	Trial #8	Trial #9
	9	1	2	8	3	7	4	6	5
1	4-way STOP No traffic (No Rum)	4-way STOP No traffic (3 Rums)	ThruS No Traffic (2 Rums)	ThruS No Traffic (3 Rums)	ThruS Traffic (No Rum)	4-way STOP no traffic (2 Rums)	ThruS Traffic (2 Rums)	ThruS Traffic (3 Rum)	ThruS No Traffic (no Rum)
	9	2	3	1	4	8	5	7	6
2	4-way STOP no traffic (No Rum)	ThruS No Traffic (2 Rums)	ThruS Traffic (No Rum)	4-way STOP no traffic (3 Rums)	ThruS Traffic (2 Rums)	ThruS No Traffic (3 Rums)	ThruS No Traffic (no Rum)	4-way STOP No traffic (2 Rums)	ThruS Traffic (3 Rum)
	9	3	4	2	5	1	6	8	7
3	4-way STOP No traffic (No Rum)	ThruS Traffic (No Rum)	ThruS Traffic (2 Rums)	ThruS NoTraffic (2 Rums)	ThruS No Traffic (No Rum)	4-way STOP no traffic (3 Rums)	ThruS Traffic (3 Rum)	ThruS No Traffic (3 Rums)	4-way STOP no traffic (2 Rums
	9	4	5	3	6	2	7	1	8
4	4-way STOP no traffic (No Rum)	ThruS Traffic (2 Rums)	ThruS No Traf (No Rum)	ThruS Traffic (No Rum)	ThruS Traffic (3 Rum)	ThruS No Traffic (2 Rums)	4-way STOP No traffic (2 Rums	4-way STOP No traffic (3 Rums)	ThruS No Traffic (3 Rums)
	9	5	6	4	7	3	8	2	1
5	4-way STOP No traffic (No Rum)	ThruS No Traffic (No Rum)	ThruS Traffic (3 Rum)	ThruS Traffic (2 Rums)	4-way STOP No traffic (2 Rums	ThruS Traffic (No Rum)	ThruS No Traffic (3 Rums)	ThruS No Traffic (2 Rums)	4-way STOP No traffic (3 Rums)
	9	6	7	5	8	4	1	3	2
6	4-way STOP No traffic (No Rum)	ThruS Traffic (3 Rum)	4-way STOP no traffic (2 Rums)	ThruS No Traffic (no Rum)	ThruS No Traffic (3 Rums)	ThruS Traffic (2 Rums)	4-way STOP no traffic (3 Rums)	ThruS Traffic (No Rum)	ThruS NoTraffic (2 Rums)
	9	7	8	6	1	5	2	4	3
7	4-way STOP No traffic (No Rum)	4-way STOP No traffic (2 Rums)	ThruS No Traffic (3 Rums)	ThruS Traffic (3 Rum)	4-way STOP no traffic (3 Rums)	ThruS No Traffic (No Rum)	ThruS NoTraffic (2 Rums)	ThruS Traffic (2 Rums)	ThruS Traffic (No Rum)
	9	8	1	7	2	6	3	5	4
8	4-way STOP No traffic (No Rum)	ThruS No Traffic (3 Rums)	4-way STOP no traffic (3 Rums)	4-way STOP No traffic (2 Rums)	ThruS NoTraffic (2 Rums)	ThruS Traffic (3 Rum)	ThruS Traffic (No Rum)	ThruS No Traffic (No Rum)	ThruS Traffic (2 Rums)
	Trial#1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6	Trial #7	Trial #8	Trial #9

RESULTS

This summary of findings in the rumble strip study has five sections, as follows:
Section 1: Comparisons
Section 2: The Effect of Rumble Strips
Section 3: Other Effects
Section 4: Analysis of Variance (ANOVA) Tables
Section 5: Qualitative results

Section 1: Comparisons

Four examples of stopping behavior are shown in the four graphs that comprise Figure 1. Each graph shows the way in which the velocity changes as the driver slows down while approaching an intersection. Of particular interest are—(1) the point at which the vehicle comes to a stop; (2) the point at which the slowdown begins; and (3) the velocity profile between these two points (i.e., the driver's braking pattern). In investigating the effects of rumble strips on stopping behavior at intersections, comparisons were made for each of these. The specific comparisons were as follows:

Comparison #1	Distance from the point at which the driver stops to the edge of the intersection.
Comparison #2	Distance from the point at which the driver begins to slow down (i.e., takes his/her foot off gas pedal) to the edge of intersection.
Comparison #3	Braking pattern

The following two ANOVAs were conducted for each of these comparisons:

ANOVA #1	Two-way vs. four-way intersection (no traffic present)
ANOVA #2	Absence vs. presence of traffic (for the two-way intersection only)

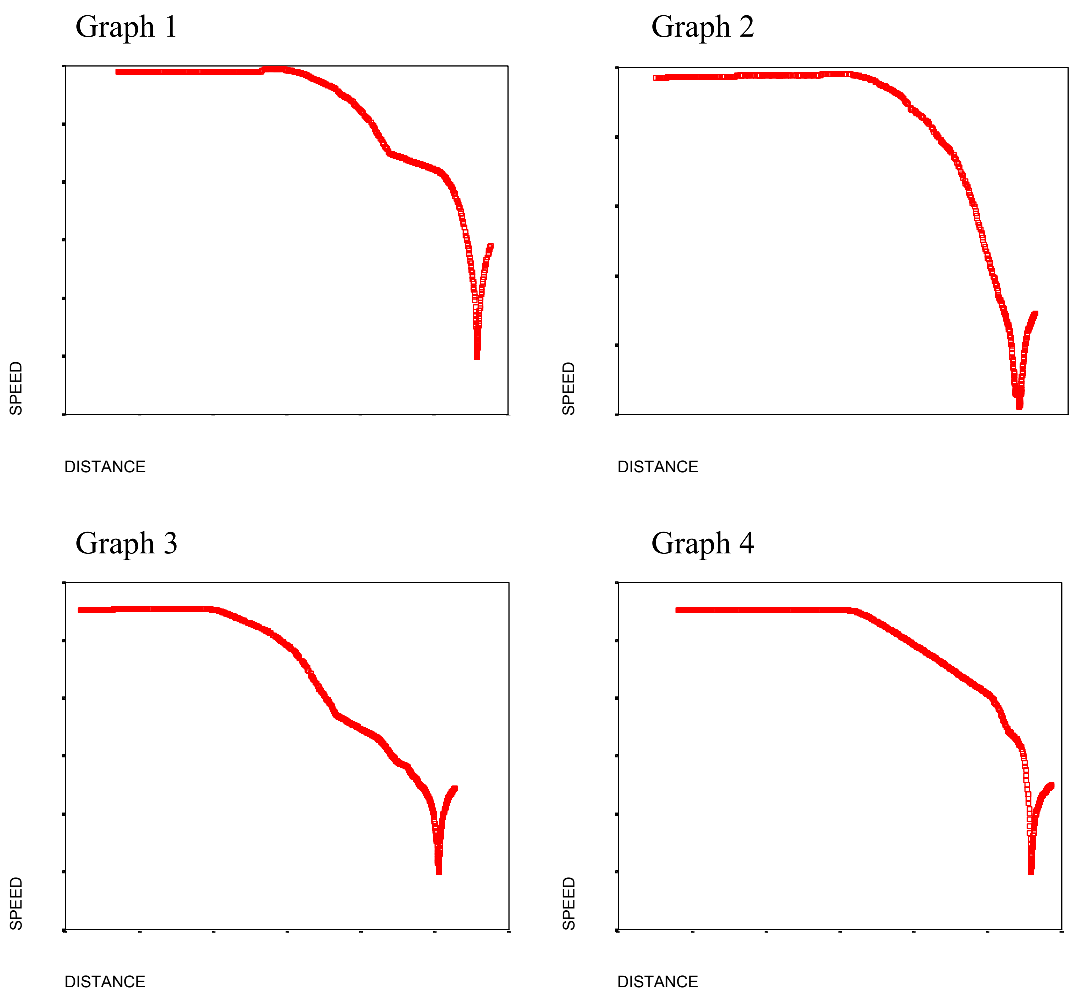

Figure 1. Four representative velocity profiles
[Note: In each case, there is a different braking pattern.]

Section 2: The Effect of Rumble Strips
There are two rumble strip variables:

- Number of rumble strips (which could be zero, two, or three).
- Type of rumble strip (full lane coverage or wheel track only).

For comparison #1, the distance from the point at which the driver stops to the edge of the intersection, we found no statistically significant different effects that could be attributed to either of these rumble strip variables for ANOVA #1 or ANOVA #2.

Similarly, for comparison #2, the distance from the point at which the driver begins to slow down (i.e., takes his/her foot off gas pedal) to the edge of intersection, we found no statistically significant different effects that could be attributed to either of these rumble strip variables for ANOVA #1 or ANOVA #2.

However for comparison #3, which deals with the braking pattern, we did find statistically significant differences that could be attributed to rumble strips in both ANOVAs.

First, in ANOVA #1 (two-way vs four-way intersection, with no traffic present), there are the following statistically significant effects:

- Number of rumble strips: p==0.0186
- Rumble strip type: $p=0.0086$
- Rumble strip type by Type of intersection (interaction between the two variables): $p=0.0206$

The effect of the number of rumble strips is shown in Figure 2, while the interaction effect can be seen by examining Figure 3.

Figure 2 shows that the difference in braking pattern related to the number of rumble strips is produced because the drivers brake more when they are further away from the intersection when rumble strips are installed than they do if there are no rumble strips.

Figure 3 shows the clear difference produced by rumble strip type—i.e., between the full coverage rumble strips (the upper curve) and wheel track rumble strips (the lower curve). It also shows that the interaction between the type of intersection and the type of rumble strip occurs because there is no difference between the two conditions for the particular case of the four-way intersection with zero rumble strips (which is the intersection that the drivers always encountered first).

Second, in ANOVA #2 (absence vs. presence of traffic, for two-way intersections only), there are the following statistically significant effects

- Rumble strip type: $p=0.0223$
- Traffic Absence/Presence by Number of rumble strips (interaction between the two variables): $p=0.034$

This ANOVA confirms that the type of rumble strip has an effect on the braking pattern—with the use of the brake being greater earlier in the slowdown process with full coverage rumble strips than it is with wheel track rumble strips.

The interaction effect is the type of statistically significant interaction that seems to have no practical importance. That is to say in this case the interaction effects should not be taken into consideration when deciding whether or not to implement rumble strips at particular intersections.

Conclusion
The presence of rumble strips has *no effect on the point at which the driver begins to slow down or on the distance away from the intersection at which he or she actually stops.* The presence of rumble strips only affects the point at which they begin to brake.

Figure 4 illustrates that, on average, the drivers in this experiment:

- Removed their foot from the accelerator when they were 1113 ft from the intersection;
- Applied their foot to the brake when they were 553 ft from the intersection;
- Stopped when they were 32 ft from the intersection.

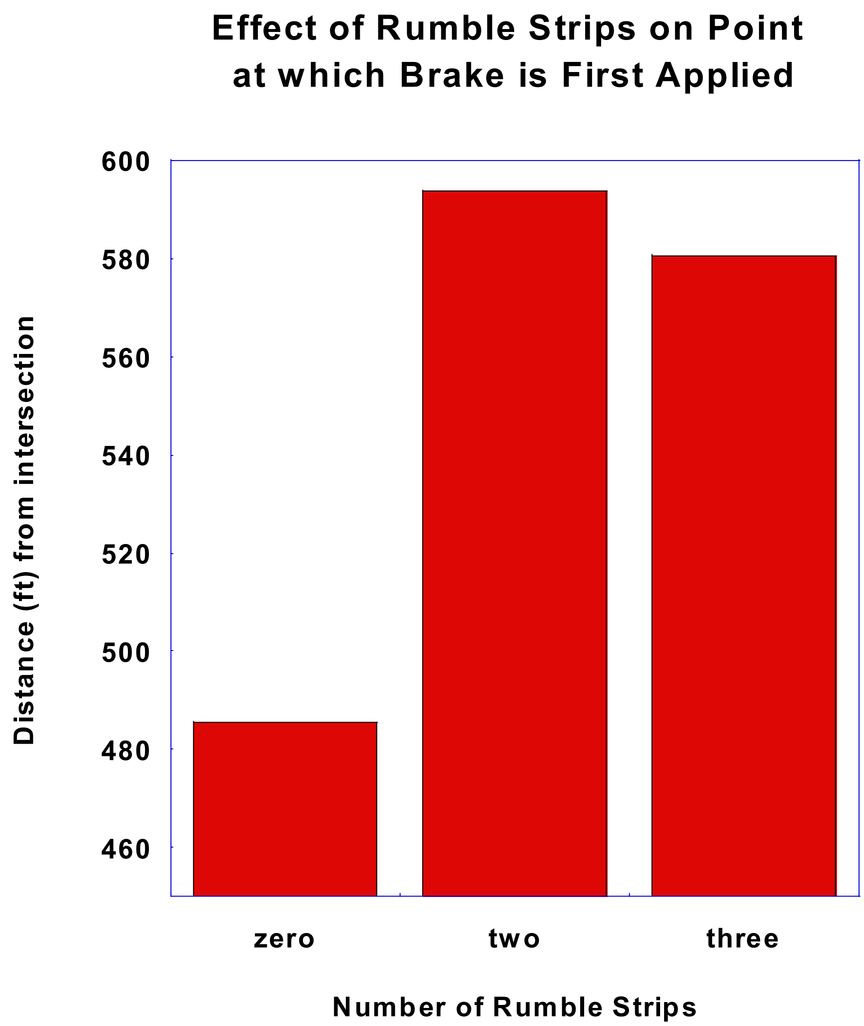

Figure 2. Point (ft from intersection) at which the driver begins to brake as a function of number of rumble strips

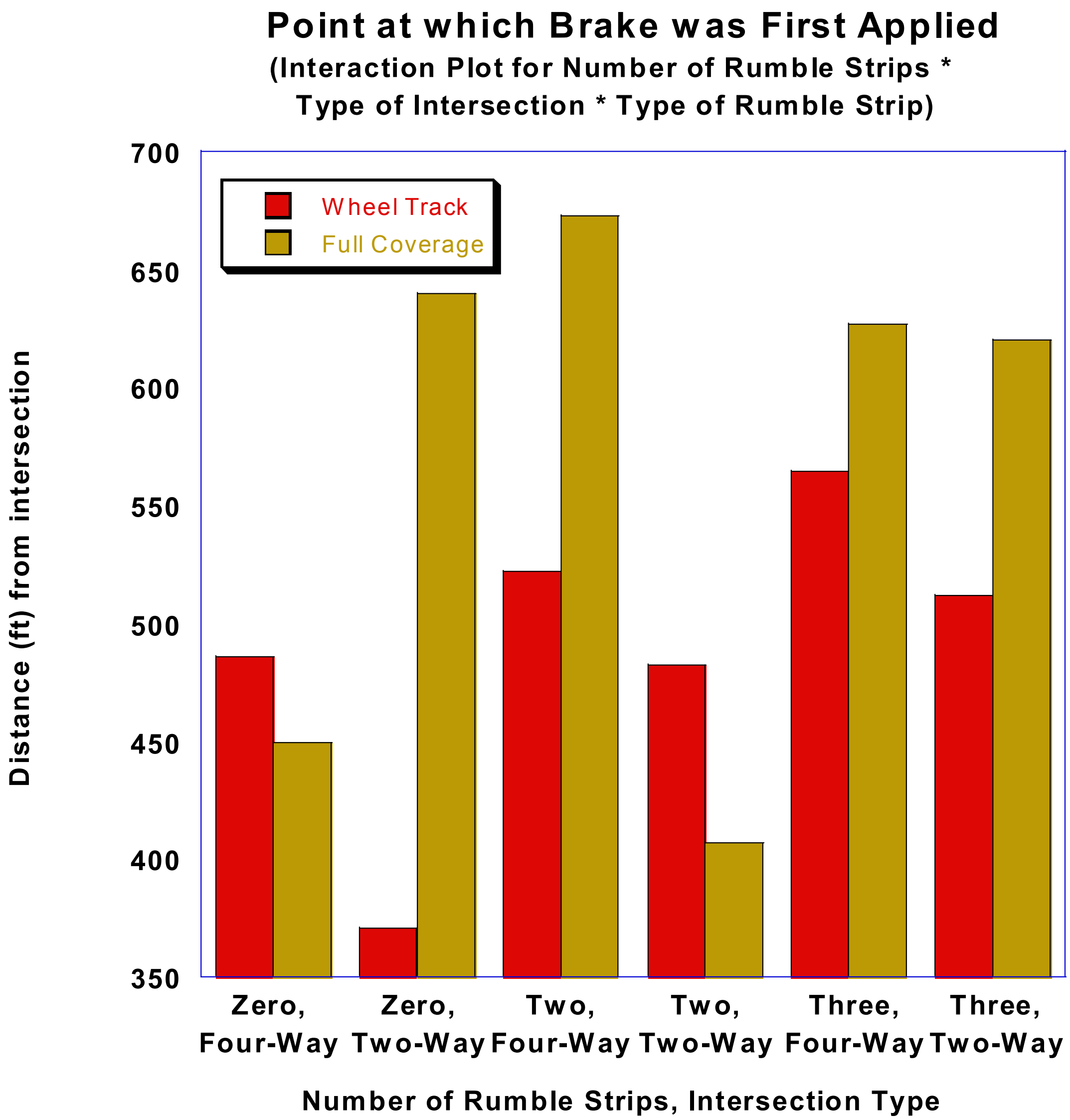

Figure 3. Point (ft from intersection) at which drivers first applied the brake as a function of number of rumble strips and type of intersection

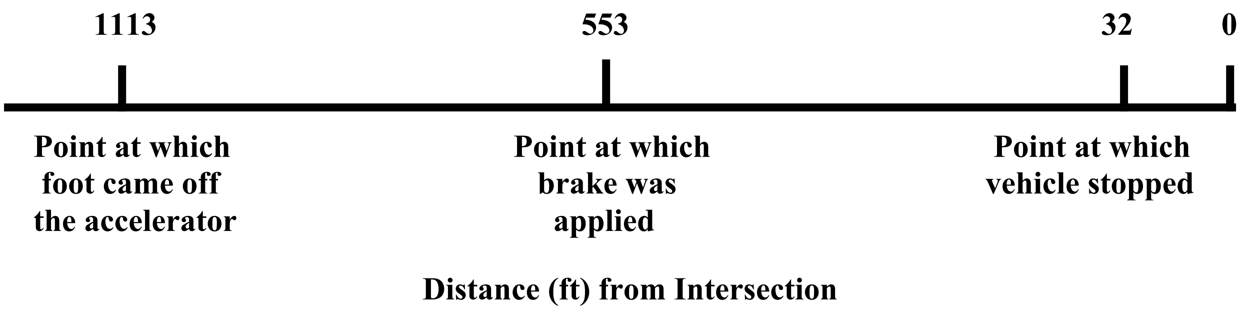

Figure 4. Illustration of temporal sequence of deceleration, braking, and stopping behavior (on average) during approach to intersection

Section 3: Other Effects
While the ANOVAs for comparisons #1 and #2 did not reveal any statistically significant results that are related to whether or not rumble strips were installed, there are other statistically significant results.

For comparison #1 (the distance from the point at which the driver stops to the edge of the intersection) the significant effects are as follows

For ANOVA #1 (the two-way vs four-way intersection, with no traffic present)

- <u>Type of intersection</u>: p=0.0045—Drivers stop nearer to the intersection (mean is 8.5 m) when they are at a four–way stop than they do when it is a two-way stop (mean is10.8 m).

For ANOVA #2 (the absence vs presence of traffic, for the two-way intersection only)

- <u>Absence/Presence of Traffic</u>: p=0.0393—When traffic is present, stopping distance is nearer to the intersection (mean is 9.25 m) than when no traffic is present (mean is 11.6 m).

For comparison #2 (the distance from point at which the driver begins to slow down—i.e., takes his/her foot off gas pedal—to the edge of intersection) the significant effects are as follows.

For ANOVA #1 (the two-way vs four-way intersection, with no traffic present)

- Number of Rumble strips: p<0.0001
- Type of intersection: p=0.0010
- Type of intersection by Number of rumble strips (interaction between the two variables): p=0.0004

While these effects would appear to be related to the presence or absence of rumble strips Figure 5 reveals that, in fact, they are not.

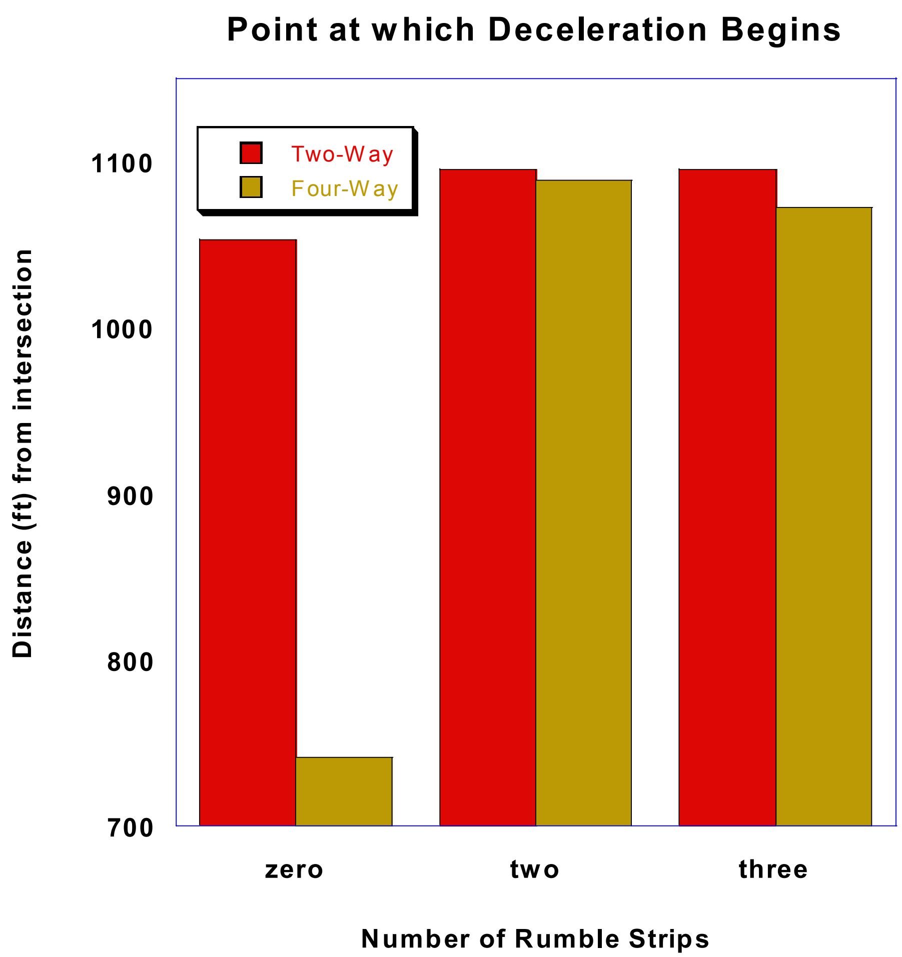

Figure 5. Point (ft from intersection) at which the driver's foot is removed from the accelerator as a function of number of rumble strips.

Inspection of Figure 4 shows that there were no differences for five of the combinations of number of rumble strips and type of intersection. Only the value for the zero rumble strip/four-way intersection combination is different. And because of the design of the experiment that combination was always experienced first. The effect, then, is seemingly an artifact of the experimental design—it is likely that it is entirely a simulator familiarization effect in that this was the first time the drivers encountered a controlled intersection in the HFRL wraparound simulator.

Finally, for ANOVA #2 (the absence vs presence of traffic, for the two-way intersection only), there are no statistically significant effects for this analysis. It is worth noting that the lack of statistical significant effects like those obtained for ANOVA #1 actually confirms the explanation just presented—since ANOVA #2 eliminates the four-way intersection that the drivers always encountered first.

Section 4: ANOVA Tables

The complete Summary tables for all six ANOVAs are presented in this section.

Comparison #1—Distance from point at which the driver stops to the edge of intersection

ANOVA #1—Two-way vs. four-way intersection (No traffic present)

ANOVA Table for Distance from Stopping Point to Intersection--Intersection Type Comparison

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Rumble Type	1	143.215	143.215	.975	.3402	.975	.145
Subject(Group)	14	2056.107	146.865				
Intersection Type	1	107.557	107.557	11.417	.0045	11.417	.895
Intersection Type * Rumble Type	1	21.941	21.941	2.329	.1492	2.329	.283
Intersection Type * Subject(Group)	14	131.887	9.421				
Number of Rumble Strip	2	.906	.453	.030	.9707	.060	.054
Number of Rumble Strip * Rumble Type	2	24.625	12.312	.810	.4549	1.620	.169
Number of Rumble Strip * Subject(Group)	28	425.521	15.197				
Intersection Type * Number of Rumble Strip	2	25.879	12.940	.902	.4172	1.804	.184
Intersection Type * Number of Rumble St...	2	56.015	28.007	1.952	.1608	3.905	.359
Intersection Type * Number of Rumble St...	28	401.649	14.345				

ANOVA #2—Absence vs. presence of traffic (for the two-way intersection only)

ANOVA Table for Distance from Stopping Point to Intersection--Traffic Comparison

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Rumble Type	1	20.903	20.903	.103	.7523	.103	.060
Subject(Group)	17	3452.325	203.078				
Number of Rumble Strip	2	39.637	19.819	.848	.4370	1.696	.178
Number of Rumble Strip * Rumble Type	2	15.514	7.757	.332	.7198	.664	.097
Number of Rumble Strip * Subject(Group)	34	794.380	23.364				
Traffic	1	159.150	159.150	4.985	.0393	4.985	.551
Traffic * Rumble Type	1	11.080	11.080	.347	.5635	.347	.085
Traffic * Subject(Group)	17	542.764	31.927				
Number of Rumble Strip * Traffic	2	23.622	11.811	.583	.5638	1.166	.136
Number of Rumble Strip * Traffic * Rumbl...	2	18.573	9.286	.458	.6362	.917	.116
Number of Rumble Strip * Traffic * Subje...	34	688.950	20.263				

Comparison #2—Distance from the point at which the driver begins to slow down (i.e., takes his/her foot off gas pedal) to the edge of intersection

ANOVA #1—Two-way vs four-way intersection (No traffic present)

ANOVA Table for Slowdown Initiation Point--Intersection Comparison

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Rumble Type	1	1690.413	1690.413	.090	.7662	.090	.060
Subject(Group)	30	563379.568	18779.319				
Number of Rumble Strips	2	144732.205	72366.102	17.920	<.0001	35.839	1.000
Number of Rumble Strips * Rumble Type	2	14911.079	7455.540	1.846	.1667	3.692	.358
Number of Rumble Strips * Subject(Group)	60	242302.404	4038.373				
Intersection Type	1	57486.691	57486.691	13.256	.0010	13.256	.956
Intersection Type * Rumble Type	1	81.765	81.765	.019	.8917	.019	.052
Intersection Type * Subject(Group)	30	130096.467	4336.549				
Number of Rumble Strips * Intersection T...	2	85537.666	42768.833	9.047	.0004	18.094	.978
Number of Rumble Strips * Intersection T...	2	11821.686	5910.843	1.250	.2938	2.501	.252
Number of Rumble Strips * Intersection T...	60	283642.231	4727.371				

ANOVA #2—Absence vs. presence of traffic (for the two-way intersection only)

ANOVA Table for Slowdown Initiation Point--Traffic Comparison

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Rumble Type	1	1342.084	1342.084	.057	.8124	.057	.056
Subject(Group)	30	702302.395	23410.080				
Traffic?	1	18337.314	18337.314	2.846	.1020	2.846	.356
Traffic? * Rumble Type	1	20.814	20.814	.003	.9551	.003	.050
Traffic? * Subject(Group)	30	193287.306	6442.910				
Number of Rumble Strips	2	11392.149	5696.074	1.057	.3540	2.113	.218
Number of Rumble Strips * Rumble Type	2	767.522	383.761	.071	.9314	.142	.060
Number of Rumble Strips * Subject(Group)	60	323464.829	5391.080				
Traffic? * Number of Rumble Strips	2	4049.871	2024.935	.409	.6658	.819	.111
Traffic? * Number of Rumble Strips * Ru...	2	6125.442	3062.721	.619	.5417	1.239	.145
Traffic? * Number of Rumble Strips * Sub...	60	296721.542	4945.359				

Comparison #3—Braking pattern

ANOVA #1—Two-way vs. four-way intersection (No traffic present)

ANOVA Table for Braking Pattern--Intersection Comparison

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Rumble Type	1	74375.916	74375.916	7.897	.0086	7.897	.786
Subject(Group)	30	282546.786	9418.226				
Number of Rumble	2	40855.822	20427.911	4.258	.0186	8.517	.725
Number of Rumble * Rumble Type	2	7818.751	3909.376	.815	.4475	1.630	.177
Number of Rumble * Subject(Group)	60	287829.045	4797.151				
Type of Intersection	1	5.192	5.192	.001	.9702	.001	.050
Type of Intersection * Rumble Type	1	21808.996	21808.996	5.978	.0206	5.978	.657
Type of Intersection * Subject(Group)	30	109441.661	3648.055				
Number of Rumble * Type of Intersection	2	3692.265	1846.132	.471	.6268	.941	.121
Number of Rumble * Type of Intersection ...	2	14995.849	7497.925	1.912	.1567	3.824	.369
Number of Rumble * Type of Intersection ...	60	235304.161	3921.736				

ANOVA #2—Absence vs. presence of traffic (for the two-way intersection only)

ANOVA Table for Braking Point--Traffic Comparison

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Rumble Type	1	71306.824	71306.824	5.812	.0223	5.812	.644
Subject(Group)	30	368090.642	12269.688				
Traffic?	1	39.002	39.002	.006	.9394	.006	.051
Traffic? * Rumble Type	1	23520.762	23520.762	3.542	.0696	3.542	.431
Traffic? * Subject(Group)	30	199237.799	6641.260				
Number of Rumble	2	16296.709	8148.354	1.897	.1589	3.794	.367
Number of Rumble * Rumble Type	2	61.481	30.741	.007	.9929	.014	.051
Number of Rumble * Subject(Group)	60	257717.408	4295.290				
Traffic? * Number of Rumble	2	32446.675	16223.337	3.558	.0347	7.116	.635
Traffic? * Number of Rumble * Rumble Ty...	2	21552.281	10776.141	2.363	.1028	4.727	.448
Traffic? * Number of Rumble * Subject(G...	60	273584.063	4559.734				

Section 5: Qualitative Results

Following their session in the driving simulator all participants completed a short questionnaire about their experience in the driving simulator. They were asked about their preference about how future intersections should be controlled. Specifically, they were asked:

> "How would you like to see intersections controlled in the future? Please check your choice below.
>
> ________with stop signs the same as now
> ________with two rumble strips and a stop sign
> ________with three rumble strips and a stop sign"

Of the participants who had the wheel track rumble strips, seven preferred "with stop signs the same as now," eight preferred "with two rumble strips and a stop sign, and one preferred "with three rumble strips and a stop sign." Results were similar for those participants who received the full coverage rumble strips: six participants expressed a preference for "with stop signs the same as now," eight preferred "with two rumble strips and a stop sign," and two preferred "with three rumble strips and a stop sign." These results indicate that the drivers who participated in this simulated driving experiment were nearly evenly split in terms of their expressed interest for maintaining the status quo and for adding two rumble strips at controlled intersections.

BRIEF DISCUSSION AND RECOMMENDATIONS FOR FUTURE RUMBLE STRIP RESEARCH

The intent of this study was to investigate the effect, if any, of rumble strips on stopping behavior at simulated rural controlled intersections. We investigated rumble strip design and deployment issues. With respect to design, we varied the rumble strip type (full width or wheel track) and with respect to deployment we varied the number of rumble strips (zero, two, or three). To test the varied aspects of design and deployment the rumble strips were tested on two different types of controlled intersections (two-way or four-way) and in the presence or absence of traffic. Results indicate that none of these manipulations seem to affect the point at which drivers stop at the controlled intersections or the point at which drivers start to slow down at controlled intersections.

The lone effect of rumble strips was observed in braking pattern. In this simulation experiment we found that drivers brake more, earlier, when they are further away from the intersection, when rumble strips are installed than they do if there are no rumble strips. Although they started to slow down at the same time and finished their braking at the same time, there was more use of the brake earlier in the slowing down maneuver in the presence of rumble strips. Results also reveal that drivers brake more, earlier when full coverage rumble strips are in place than they do when wheel track rumble strips are installed. This result seems to indicate that rumble strips are likely to cause drivers to use their brakes more, earlier and in turn perhaps entails safer, more controlled, braking behavior at rural controlled intersections. However, there may be a downside: more early braking could be associated with increased rates of rear end collisions from cars that are following and not expecting to brake so soon. Before further implementation of rumble strips it would be worth investigating whether the possible safety benefit of earlier braking at rural intersections (outfitted with rumble strips) outweighs the possible higher incidence of rear end crashes.

After considering these results, it is worth conducting additional research—perhaps under conditions in which rumble strips are likely to be more effective, such as their effect on sleep-deprived drivers and at sight-limited intersections. These could not be tested in the just-completed driving simulator study because of financial and simulator restrictions.

Participants in the study reported here were not deliberately sleep-deprived when they drove the experimental route—it would be interesting to observe whether or not rumble strips affect sleep deprived drivers' stopping behavior.

It would also be interesting to investigate whether rumble strips placed at sight-limited intersections are effective warning tools. The new driving simulator scheduled for delivery later this year would allow us to test sight-limited intersections.

REFERENCE

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