OBSTACLE AVOIDANCE MANEUVERS IN AN AUTOMOBILE SIMULATOR

Lisa D. Adams
Michael J. Flannagan
Michael Sivak

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-95-3
April 1995

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-95-3		

4. Title and Subtitle Obstacle avoidance maneuvers in an automobile simulator	5. Report Date April 1995 6. Performing Organization Code 304127
7. Author(s) Lisa D. Adams, Michael J. Flannagan, and Michael Sivak	8. Performing Organization Report No. UMTRI-95-3
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A	10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address ITS Research Center of Excellence The University of Michigan 200 Engineering Programs Building 2609 Draper Drive Ann Arbor, Michigan 48109-2140 U.S.A	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

The ITS Research Center of Excellence is a program of collaborative efforts for the advancement and application of ITS technologies. The Center is supported through fees from industrial members, as well as grants and contracts from local, state, and the U.S. DOT.

16. Abstract

This study was conducted to determine the strategy subjects use to avoid a rock in the middle of their lane with a preview distance of 49 m at 89 km/h. In a driving simulator we observed subjects' performance in an unalerted situation (one trial per subject), and changes in their behavior over repeated (alerted) trials. There were twelve subjects divided equally by sex and age (younger, middle-aged, and older).

For the unalerted trial, eight subjects steered only, three subjects braked and steered, and one subject braked only. Five subjects avoided hitting the rock, all by steering only. Sex of the subject did not affect strategy; however, younger subjects steered more than older subjects.

For the repeated trials, subjects were informed that a rock would be in the road about 50% of the time for the remainder of the experiment. Each subject encountered the rock 17 times. We found that on 51% of the trials the subjects braked and steered, on 46% steered only, and on 3% braked only. Subjects who braked and steered had the highest success rate for missing the rock (96%), followed by those who steered only (67%), and those who braked only (0%).

The potential for active control of the vehicle in emergency situations will be improved by information about the types of maneuvers a driver is likely to execute and under what circumstances (speed, preview distance, etc.) they are executed. However, whether the supporting information can be provided by data from driving simulators or only from actual driving remains to be determined.

17. Key Words	18. Distribution Statement
obstacle avoidance, accidents, braking, steering, driving, vehicle control, simulator	Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	23	

Acknowledgments

Appreciation is extended to Paul Green, Brian Davis, and Patrick Wei for their assistance with the UMTRI driving simulator.

Contents

Introduction

To avoid an obstacle in their lane drivers must react by altering their speed and/or their lateral position. The strategies that drivers adopt—and whether those strategies are successful—will depend on several factors, including road conditions, preview distance to the object, and handling characteristics of the vehicle. The outcome will also depend on drivers' understanding of the aforementioned factors, their ability to incorporate that information into decisions under time pressure, and any heuristics they have for selecting strategies under time pressure. What drivers actually do given their own cognitive constraints may differ in systematic ways from what is possible given the handling characteristics of the vehicle. Understanding of what drivers actually do in emergency situations can aid the development of future Intelligent Transportation Systems (ITS). The potential for active control of the vehicle in emergency situations will be improved by information about the types of maneuvers a driver typically executes and under what circumstances they are executed. If the system recognizes an emergency situation for which it is known that the driver will probably not execute a physically possible braking, steering, or braking-and-steering maneuver, the system may be programmed to take control of the vehicle and execute the maneuver. Furthermore, there may be differences in strategy that can be attributed to a driver's age, sex, and driving experience and not just to individual differences. If this is the case, programs modeling the expected type of maneuver for a driver with certain characteristics may be developed to further personalize the system.

A recent review of the literature related to obstacle avoidance maneuvers (Adams, 1994) revealed three studies conducted at 56 mph (90 km/h). The subjects in a simulator study by Lechner and Malaterre (1991) encountered a vehicle stopped in their lane at an intersection. The results indicated that 49% of their subjects braked and steered, 39% braked only, and 12% steered only. Furthermore, the preference for braking increased with an increase in the time-to-collision. Drivers who steered had higher success avoiding the obstacle than those who attempted braking maneuvers. In a related study (Malaterre, Ferrandez, Fleury, and Lechner, 1988), subjects were shown a videotape of a situation at an intersection prior to a collision and slides of the collision itself. Subjects said they would steer when their vehicle was a shorter distance from the obstacle, when they had certainty about the obstacle's trajectory, and when there were conditions of good visibility. Rice and Dell'Amico (1974) found that 56% of subjects braked and steered, 29% braked only, and 12% steered only when a large plastic barrel was ejected onto the subjects' path. Only one driver avoided hitting the barrel by steering; however, this driver was traveling at only 43 mph (70 km/h). Based on these studies at typical expressway speeds, drivers tend to combine both braking and steering. The next most frequent strategy is to brake only, and the least frequent strategy is to steer only.

A fourth study (Malaterre, Peytavin, Jaumier, and Kleinmann, 1987) was conducted at speeds between 25-75 (40-120 km/h). Subjects had to indicate the limit beyond which it would be too late to avoid an obstacle by braking or making a lateral movement. The study found that subjects generally felt steering maneuvers could be executed nearer the obstacle than braking maneuvers. Furthermore, Limpert and Gamero (1974), in an analysis of 3,000 accidents, found that the number of drivers who use steering maneuvers to avoid a collision increases with speed.

The present study was conducted to determine the strategies subjects use to avoid an obstacle on the road with a limited preview distance at a relatively high speed, and to investigate whether these strategies are influenced by driver age and sex. In a driving simulator we observed subjects' performance in an unalerted situation (one trial per subject), and changes in their behavior over repeated (alerted) trials. The simulator offered flexibility when designing the emergency situation, such as the type and size of the obstacle, preview distance to the obstacle, and location of the obstacle.

Method

Subjects

There were 12 subjects: 4 in a younger group (aged 16-19 years with a mean of 18), 4 in a middle-aged group (aged 31-47 years with a mean of 38), and 4 in an older group (aged 64-70 with a mean of 67). The groups were divided equally by sex. By self-report, the annual driving mileage ranged from 3,000 to 20,000 miles (4,830 to 32,000 km), with a mean of 10,514 miles (16,928 km). The subjects were paid for their participation and they were all licensed, active drivers. None had previous experience driving a simulator.

Equipment

Figure 1 summarizes the laboratory setup used in this experiment. The simulator, located at the University of Michigan Transportation Research Institute (UMTRI), consists of two Apple Macintosh workstations (a Quadra 840 and a Power Macintosh 8100/80 with Macintosh color displays), a color projection system (3M 9550 Overhead Projector and a Sharp Computer Projection Panel, QA-1650), a screen (3M Hi-White Encapsulated Reflective Sheeting), a laboratory buck, steering wheel, brake pedal, accelerator pedal, digital speedometer, and sound equipment (including two JBL Control Micro Speakers in the dash and one under the driver's seat). The simulator code is written in the C programming language and uses the Toolbox routines and Mac Quickdraw graphics for the scene displays (MacAdam et al., 1993). The Macintosh Quadra 840 controls the sound system through a stereo receiver and graphic equalizer, and the Power Macintosh controls the graphics display. The frame rate for display of graphics is between 12 and 25 frames per second, depending on the size of the scene projection and amount of detail. Ambient lighting in the laboratory was kept low while subjects drove to avoid washing out the simulator screen.

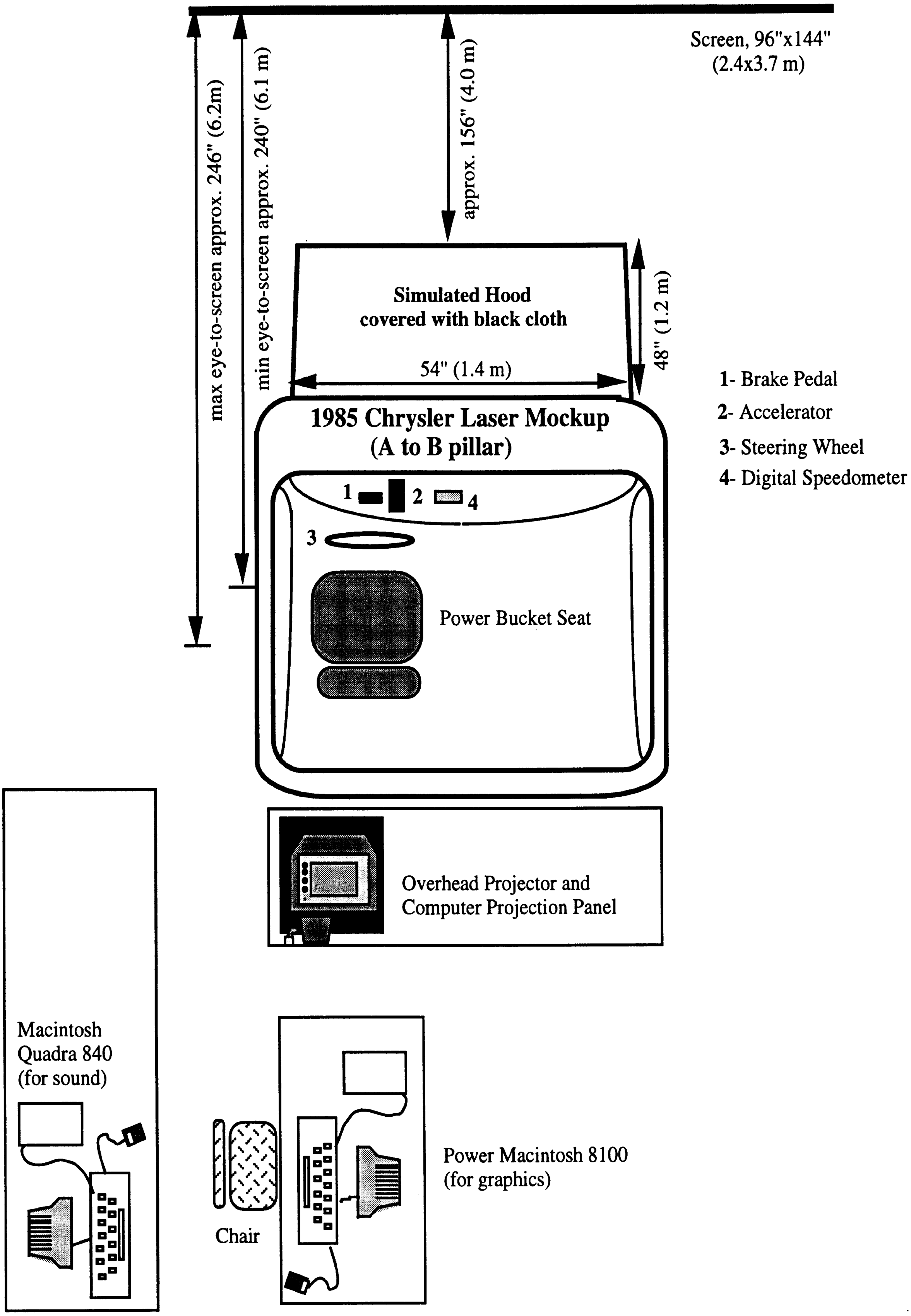


Figure 1. Schematic diagram of laboratory setup.

Graphics

The road and scenery were projected onto a screen using a color LCD projection panel. Roads were composed of segments, normally 30 feet (9.1 m) in length. Twenty such segments can be visible on the screen at one time, although the road geometry may mask some segments. For instance, preview distance will decrease if there is a hill. Each road segment is described by a heading and gradient. A graphics library allows each segment to be enhanced by one object, such as another vehicle, sign, tree, animal, or barn. If the subject's vehicle collides with an object, the vehicle passes through the object as if it were not there. The two-lane road designed for this experiment was 24 feet (7.3 m) in width. It consisted of straight portions, curves, and hills. The background scenery for the simulator can also be modified. For this experiment the background was a mountainous scene.

Procedure

Subjects were run in individual sessions that lasted approximately one hour each. Their actual driving time in the simulator was about 40 minutes. The subjects were asked to drive as if they were alone and not to converse with the experimenter unless they had questions. The session was divided into three sections. Before the first section, subjects were instructed to adjust the seat in the laboratory buck as they normally would in a car. The first section was designed as a warm-up period to familiarize the subjects with the simulator. Subjects were given a brief introduction to the simulator's setup. They were instructed first to become familiar with the simulator's driving characteristics (steering, braking, accelerating, and decelerating) before following the speed limit signs. They were told to indicate verbally each time they saw a deer crossing sign. This task was assigned to keep up the subjects' level of arousal and to alleviate boredom. After the instructions were given, the laboratory lights were turned off and the subjects began driving. Subjects completed the first section, a 13.5 mile (21.7 km) road, in approximately 15 minutes. A stop sign in the middle of the lane indicated to the subjects the end of the first section. After subjects stopped, the laboratory lights were turned on and they were allowed to step out of the laboratory buck.

After a five-minute break the second section began. Subjects were given the same task as in the first section–to indicate verbally when they saw a deer crossing sign. After the instructions were given, the laboratory lights were turned off and the subjects began driving. After approximately three to four minutes of driving, they encountered a rock in the middle of their lane. The center of the rock was located 7 feet (2.1 m) to the right of the centerline. In order for the rock to be a surprise to the subjects, a hill was used to limit the preview distance to the rock to 162 feet

(49.4 m). Figure 2 depicts a scene climbing the hill, and Figure 3 depicts a scene with the rock in full view. The posted speed limit at the time the rock was encountered was 55 mph (89 km/h). Shortly after the rock (but far enough that it was not visible when the rock was encountered) there was a stop sign in the middle of the lane indicating to the subjects to stop. After the subjects stopped, the laboratory lights were turned on and the subjects were given further instructions.

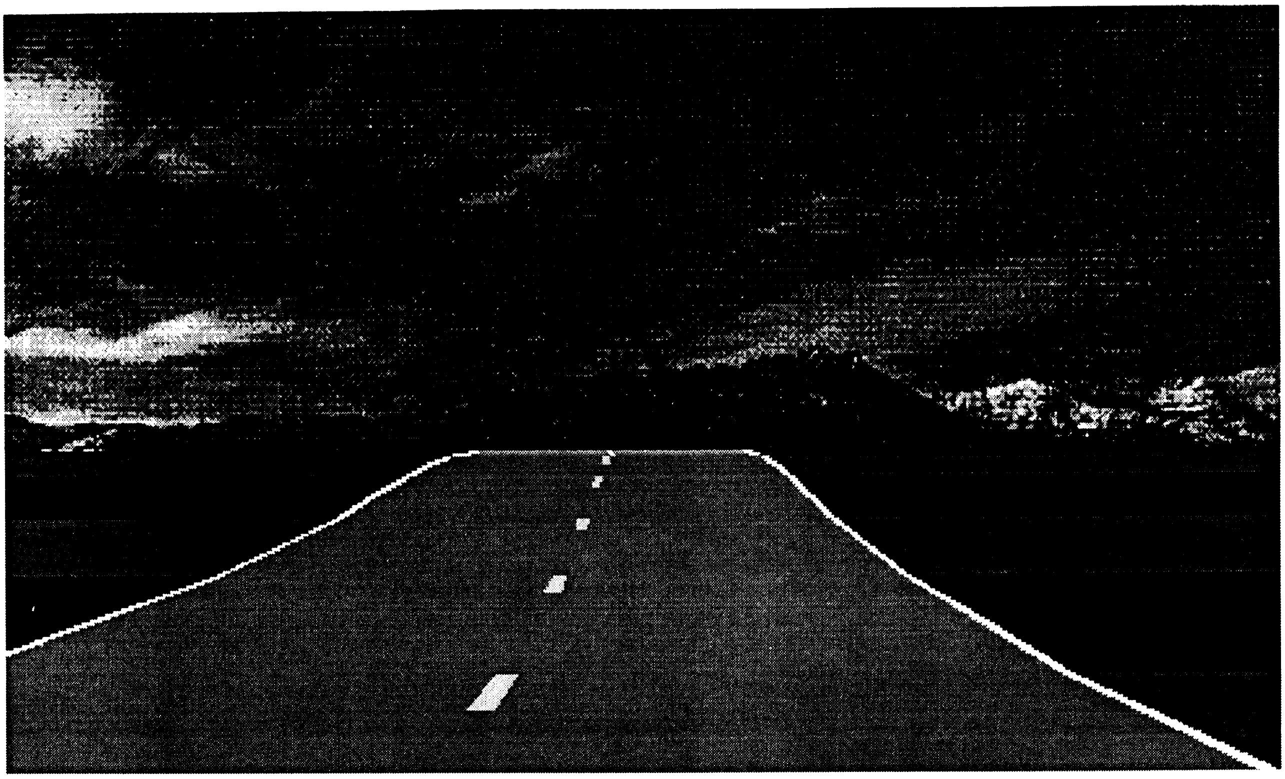


Figure 2. View of climbing the hill.

Figure 3. View of the rock on the road.

Subjects were informed that for the remainder of the experiment they would repeatedly drive a segment of road that had a rock in the middle of their lane after cresting a hill, and that this obstacle would be present about 50 percent of the time. They were shown a picture of the repeated segment, similar to Figure 4. The subjects were informed that there were no deer crossing signs for this section of the experiment. The posted speed limit for the repeated segment was 55 mph (89 km/h). Subjects were told not to begin an avoidance maneuver before they first saw the rock. They were told that premature movements, in anticipation of the rock's presence, were recorded in a data file and noted by the experimenter. The first 17 loops were analyzed for each subject. The order of the loops was randomized once and presented to each subject in the same random order. A stop sign in the middle of the lane indicated the end of the section. All subjects completed a questionnaire following the session.

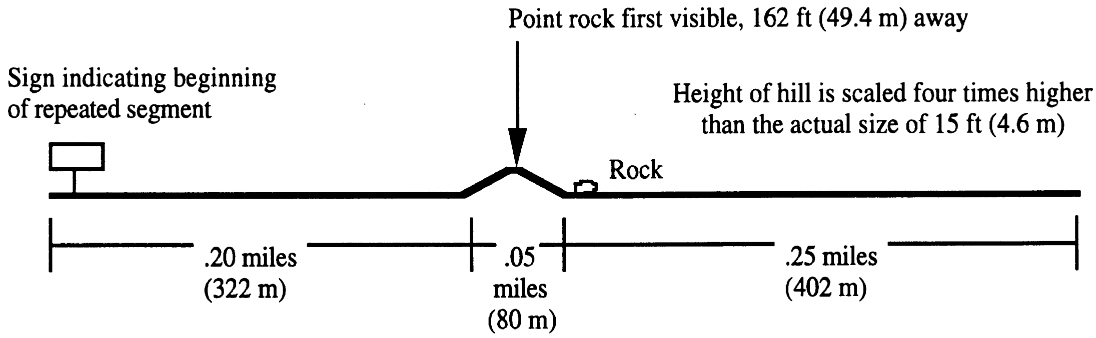


Figure 4. Diagram of the repeated segment.

Driving Performance

The data file included the following information: the longitudinal position of the car on the road from the start of the loop, lateral position of the center of the car from the centerline, the throttle (accelerator) position, the speed (in feet/second), and the position of the brake pedal. Deceleration without braking was defined in this experiment as a reduction in speed (without braking) by at least 2 mph (3.2 km/h) over the 162 feet (49.4 m) separation between the point the obstacle was first visible and the actual location of the obstacle. The speed was recorded at the point the obstacle was first visible to the subject, not the point at which the subject first reacted. In order for the subjects to avoid the obstacle, the center of a vehicle 5.5 feet (1.7 m) wide (as used in this experiment) had to be less than 3.0 feet (0.9 m) from the centerline, if they were steering around to the rock's left, and 11.0 feet (3.4 m) from the centerline if they were steering to the right. [The rock was 2.5 feet (0.8 m) wide and 1.5 feet (0.5 m) high.] This, incidentally, allowed the subjects to avoid the obstacle while remaining in their lane if they steered to the left.

Lateral movements were defined as moving a distance of at least one foot (0.3 m), right or left, from the average position in the lane. The average position was determined by computing the average distance from the vehicle's center to the centerline for the 150 feet (45.7 m) prior to the point where the obstacle was first visible. This computation was made only for the unalerted trial. For the repeated trials, a visual inspection of the lateral movements was made.

Questionnaire

After driving the simulator, subjects were given a questionnaire regarding their driving strategies and their reaction to the simulator. The questions on strategy, shown in Table 1, included how the subjects thought they would normally react to obstacles in their path, if they had ever encountered a situation similar to the one presented during the experiment, whether they changed their driving strategy as they encountered the obstacle repeatedly, and whether they would apply a strategy they learned in the simulator to a real driving situation. Questions on their reactions to the simulator are summarized in Figure 5. The subjects rated the simulator's quality of detail, quality of movement, steering inputs, braking inputs, accelerator inputs, sound, and compared the simulator to an actual car.

Table 1. Section of questionnaire relating to driving strategy.

• How do you think you would normally react to obstacles in your path when you're driving a car (steering, braking, combination of steering and braking, etc.)? Did you react differently in the simulator? If so, why?
• Have you ever encountered a situation similar to the one presented to you today? Was the simulated situation realistic? Please explain.
• As you encountered the obstacle over and over again, did you change your driving strategy to avoid the obstacle, or did your strategy stay the same?
• If you found a strategy driving the simulator which allowed you to always avoid the obstacle, would you apply that strategy in a real driving situation to help you avoid the obstacle?

Was the simulator easier, the same, or harder to drive than an actual car?

Easier | Same | Harder

Did you feel that the simulator was like "real" driving, compared to an actual car?

Very Real | Okay for this Study | Very Unreal

Rate the visual quality of the simulator: quality of detail:

Very Good | Okay for this Study | Very Bad

Rate the visual quality of the simulator: quality of movement:

Very Good | Okay for this Study | Very Bad

Steering Inputs:

Too Sensitive | Just Right | Not Sensitive Enough (sluggish)

Braking Input:

Too Sensitive | Just Right | Not Sensitive Enough (sluggish)

Accelerator Input:

Too Sensitive | Just Right | Not Sensitive Enough (sluggish)

Sound:

Very Real | Okay for this Study | Very Unreal

Please relate your experience of driving the simulator compared to the feeling you have driving an actual car:

Figure 5. Section of questionnaire relating to quality of simulator.

Results

Unalerted Trial

Table 2 summarizes the strategies used for the unalerted trial. Eight of the 12 subjects steered only, three subjects braked and steered, and one subject braked only. Nine of the subjects also decelerated without braking. Five of the subjects avoided the rock. All five steered only, while two of them also decelerated without braking.

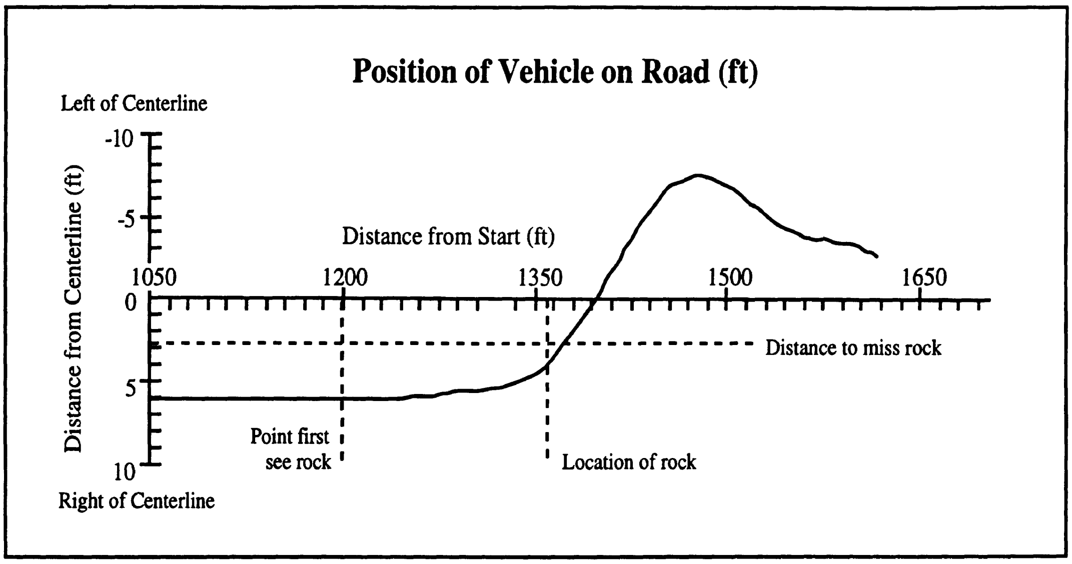
Table 2. Results of the first, unalerted trial.

		Steer *Yes*	*No*
Brake	*Yes*	3	1
	No	8	0

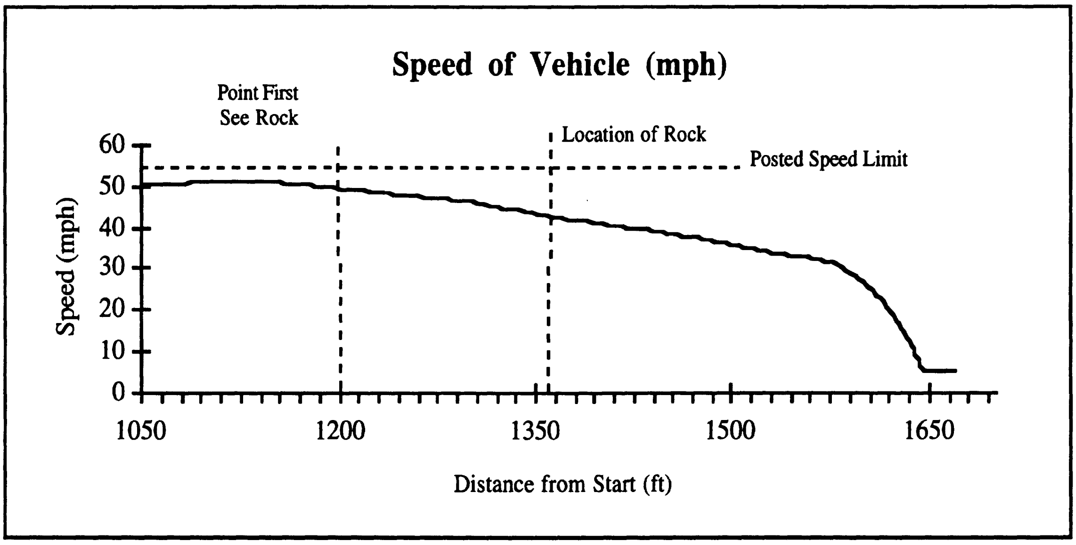
As an example, Figure 6 describes the behavior of one subject on the unalerted trial. In order to avoid the rock, the subject had to position the center of the car no more than 3.0 feet (0.9 m) to the right of the centerline at a point 1,362 feet (415 m) from the beginning of the loop. The point at which the subject could first see the rock was 1,200 feet (366 m). Panel A describes the lateral position of this subject. The subject slowly began a lateral movement at approximately 1,275 feet (389 m). The rate of the lateral movement increased at approximately 1,340 feet (408 m). At 1,362 feet (415 m), the position of the rock, the vehicle's center was still approximately 3.7 feet (1.1 m) to the right of the centerline, meaning that the vehicle hit the rock. Subjects received no immediate feedback about whether they had avoided the rock because the simulator allowed the vehicle to pass through objects.

Beyond 1,362 feet (415 m) the subject drove into the opposing lane, continuing the lateral movement. Panel B describes the speed of the subject. The subject was driving at approximately 50 mph (80 km/h) when the rock was first visible. The subject decelerated without braking, braked, then continued to decelerate without braking. Panel C describes the braking of the subject. A yes or no on the graph indicates whether or not pressure was placed on the brake pedal. This subject braked at approximately 1,305 feet (398 m) and again at 1,500 feet (457 m)

A



B



C

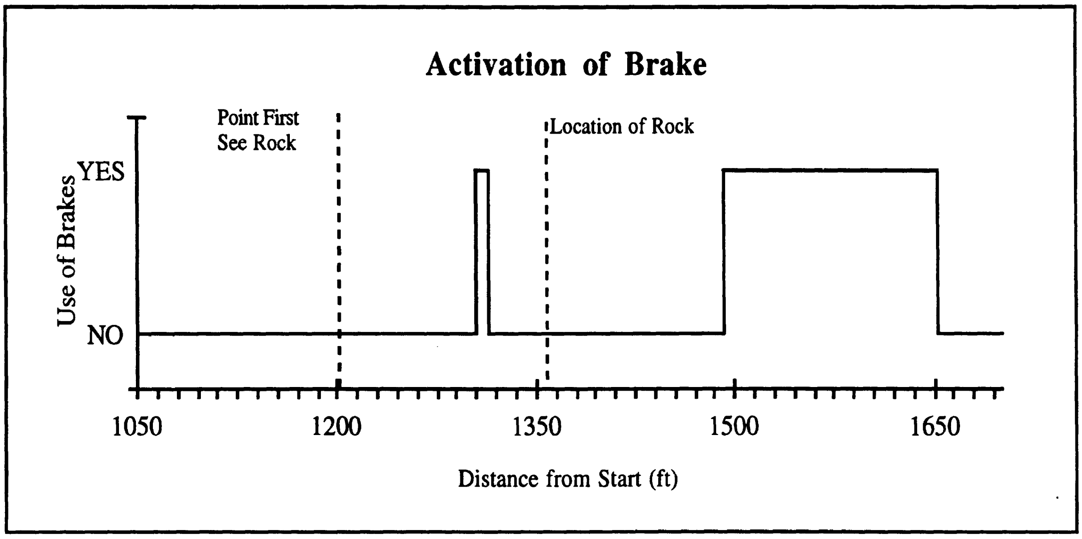


Figure 6. Description of one subject's strategy to avoid the rock.

Table 3 summarizes the action taken on the first, unalerted trial. These data indicate that steering only was used more often by the younger and middle-aged subjects, in comparison to the older subjects. Sex of the subject did not significantly affect strategy.

Table 3. Results of the first, unalerted trial by age and sex.

	Younger	*Middle-aged*	*Older*	*Male*	*Female*
Steer	4	3	1	3	5
Brake	0	0	1	1	0
Both	0	1	2	2	1

Table 4 is a summary of each subject, of the average lateral position from the center of their vehicle to the centerline (determined by the 150 feet (45.7 m) prior to the point where the obstacle was first visible), and the speed at the point where the obstacle was first visible. Three of the older subjects and one of the middle-aged subjects drove slower than the speed limit. One subject in the younger group drove faster than the speed limit. The eight subjects who steered for the unalerted trial were traveling at an average speed of 55 mph (89 km/h), while the subjects who included braking in their maneuver traveled an average speed 46 mph (74 km/h).

Table 4. Summary, for each subject, of the average lateral position from the centerline before the obstacle is visible, and speed at the point where the obstacle is first visible.

Subject	*Age Group*	*Lateral Position (ft)*	*Speed (mph)*
1	Younger	4.4	55
2	Younger	3.1	59
3	Younger	5.2	55
4	Younger	4.6	55
5	Middle-aged	5.3	49
6	Middle-aged	6.4	56
7	Middle-aged	5.0	54
8	Middle-aged	4.9	56
9	Older	5.9	42
10	Older	7.2	41
11	Older	4.5	55
12	Older	5.8	50

Alerted/Repeated Trials

Table 5 provides the breakdown of steering and braking for the repeated trials. There were a total of 204 encounters with the obstacle (17 trials for each of 12 subjects). Steering and braking-and-steering maneuvers were executed the most. The average speed for subjects who steered only was 54 mph (87 km/h) and for subjects who included braking, 50 mph (80 km/h). [The posted speed limit was 55 mph (89 km/h).]

Table 5. Results of the repeated (alerted) trials.

		Steer	
		Yes	*No*
Brake	*Yes*	103	7
	No	94	0

Table 6 summarizes the repeated trials by hit and misses. The number of obstacles hit decreased as the trials progressed, as shown in Figure 7. One subject hit the obstacle all 17 times and another subject hit the obstacle 14 times, combining for 74% of all hits.

Table 6. Breakdown of the repeated (alerted) trials by hits and misses.

		Steer	
	HITS	*Yes*	*No*
Brake	*Yes*	4	7
	No	31	0

		Steer	
	MISSES	*Yes*	*No*
Brake	*Yes*	99	0
	No	63	0

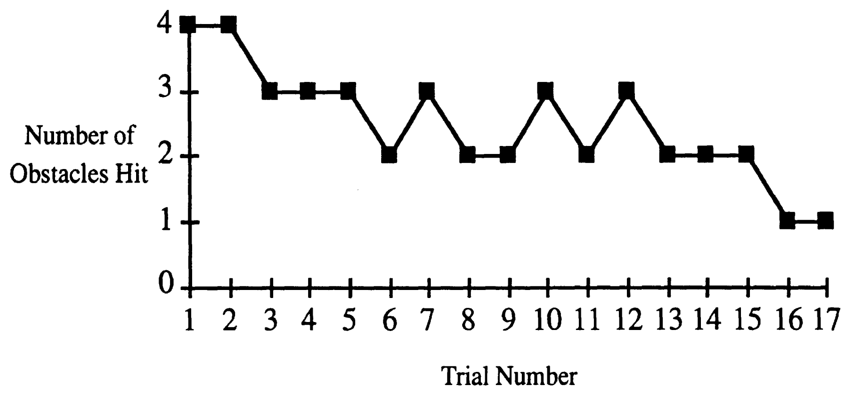


Figure 7. Number of obstacles hit as repeated (alerted) trials progressed.

Table 7 is a breakdown of the maneuvers by age and sex. As indicated above, two subjects continually hit the obstacle. One relied on the same strategy for every trial (and hit 14) and the other braked every time, sometimes including steering and decelerating without braking. Most subjects executed the same maneuver (or a slight variant) each time.

Table 7. Results of the repeated (alerted) trials by age and sex.

	Younger	*Middle-aged*	*Older*	*Male*	*Female*
Steer	56	12	26	59	35
Brake	0	1	6	0	7
Both	12	55	36	43	60

During the first encounter with the rock in the repeated segment trials, more people braked than for the unalerted trial. For the unalerted trial, one subject braked and three subjects braked and steered, while for the first encounter during the alerted/repeated trials, one subject braked and eight subjects braked and steered. Six subjects did not change their strategy (three in the younger group, one in the middle-aged group, and two in the older group), but three of these six did decelerate for the unalerted trial and not for the alerted trial. A comparison of the strategies for the unalerted trial and the first alerted trial is shown in Table 8.

Table 8. Comparison of the unalerted trial and the first repeated (alerted) trial.

	Unalerted Trial	First Alerted Trial
Steer	8	3
Brake	1	1
Both	3	8

Selected Questionnaire Results

Ten subjects said they normally react to obstacles in their path by braking and steering. No subjects said they normally react by braking alone. Six of the subjects said their reaction in the simulator was different than a normal car mostly because the simulator did not react as well as a car. Eight subjects had encountered a situation similar to the one presented in the simulator, and seven responded that the situation presented was realistic (four subjects did not say whether or not the situation was realistic).

Results from the questionnaire also indicated that *all* of the subjects felt the simulator was harder to drive than an actual car. No subject rated the steering inputs as "Just Right" and only four subjects rated the braking and accelerator inputs as "Just Right." Eleven of the subjects rated the quality of visual detail between "Okay for this Study" and "Very Good." Six subjects rated the quality of visual movement between "Okay for this Study" and "Very Good." Sound was rated by eight of the subjects between "Okay for this Study" and "Very Real."

Discussion and Conclusions

The dominant strategy subjects used to avoid the rock for the unalerted trial was to steer. Unlike the previous studies (Lechner and Malaterre, 1991; Rice and Dell'Amico, 1974) in which only 12% of their subjects steered, 67% of our subjects steered without braking, and 92% included steering in their maneuver. However, in the earlier studies the obstacles were larger than in the present study (a car and a large barrel vs. a rock), and that could explain the different strategies employed.

The eight subjects who steered only were driving faster than the subjects who braked or braked and steered. As reported by Adams (1994), the tendency to steer is greater at higher speeds and at shorter distances from the obstacle, while the tendency to brake is greater with more time.

Five of the subjects avoided the obstacle on the unalerted trials, all by steering only. However, the subjects' initial lateral position may have affected their success in avoiding the obstacle. Subjects who drove closer to the centerline had a shorter distance to move to avoid the obstacle. For the unalerted trial, the five subjects who avoided the obstacle were an average of 4.7 feet (1.4 m) from the centerline (when the obstacle was first visible), while the subjects who hit the obstacle were an average of 5.6 feet (1.7 m).

Most subjects steered only when they first encountered the rock in the middle of their lane. However, after being alerted about the repeated segments with the obstacle, the number of subjects who braked on the first alerted trial was higher. The success rate also increased from the unalerted trial. Eight of the subjects avoided the obstacle (compared to five for the unalerted trial). The mean speed for the 12 subjects also decreased from the unalerted trial (52.2 mph [84.0 km/h]) to the first alerted trial (49.6 mph [79.9]).

The results of the unalerted trial indicate that sex did not affect the strategy executed by the driver. However, age affected the strategy used. Specifically, the younger subjects steered more than the older ones.

On the alerted trials, the preferred strategy was braking and steering (50.5%), followed by steering only (46.1%) and braking only (3.4%). Braking and steering had the highest success rate for missing the rock (96%), followed by steering only (67%), and braking only (0%).

The high frequency of relying on steering might have been influenced by the lack of any oncoming traffic. Oncoming traffic would likely increase the use of braking because of the need to reduce excursions into the oncoming lane of travel.

Results from the questionnaire suggest that subjects did not feel that the simulator was like an actual car. Consequently, the strategy they executed in the simulator may have been affected by the characteristics of the simulator. The present simulation also differs from actual driving in the nature of the risk involved and in the consequences of not being able to avoid obstacles. This problem is inherent, to a certain degree, in all simulations. Consequently, of highest priority for future research, is a study that would validate that driver responses to emergency situations in a simulator are fundamentally comparable to those in actual driving. While that is likely to be the case when using extremely high-fidelity simulators along with realistic payoff matrices, the practical issue is to determine the minimum level of fidelity (in both the hardware and payoff matrices) that is required for that to occur.

References

Adams, L.D. (1994). *A review of the literature on obstacle avoidance maneuvers: Braking versus steering* (Technical Report UMTRI-94-19). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Allen, R.W. (1994). The driver's role in collision avoidance systems. In *Workshop on Collision Avoidance Systems*. Reston, VA: IVHS AMERICA Safety & Human Factors Committee.

Lechner, D., & Malaterre, G. (1991). Emergency maneuver experimentation using a driving simulator (Report No. SAE 910016). Presented at *Autotechnologies, 5th Conference and Exposition*. Monte Carlo, Monaco.

Limpert, R., & Gamero, F.E. (1974). The accident avoidance potential of the motor vehicle: Accident data, vehicle handling and safety standards. In *Proceedings of the Third International Congress on Automotive Safety*, Volume II. Washington D.C.: GPO.

Malaterre, G., Ferrandez, F., Fleury, D., & Lechner, D. (1988). Decision making in emergency situations. *Ergonomics*, *31*, 643-655.

Malaterre, G., Peytavin, J.F., Jaumier, F., & Kleinmann, A. (1987). *L'estimation des manoeuvres realisables en situation d'urgence au volant d'une automobile* (Report No. 46). Joinville, France: INRETS.

MacAdam, C.C., Green, P.A., & Reed, M.P. (1993). An overview of current UMTRI driving simulators. *UMTRI Research Review*, *24*, (1), 1-8.

Rice, R.S., & Dell'Amico, F. (1974). *An experimental study of automobile driver characteristics and capabilities* (Report No. ZS-5208-K-1). Buffalo, NY: Calspan.