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NHTSA Light Vehicle Antilock Brake System Research Program Task 5.2/5.3:

Test Track Examination of Drivers' Collision Avoidance Behavior Using Conventional and Antilock Brakes

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16. Abstract

Numerous crash data statistical analyses conducted over the past few years suggest that, for automobiles, the introduction of four-wheel antilock brake systems (ABS) has produced net safety benefits much lower than originally expected. The studies indicate the apparent increase in single-vehicle crashes involving passenger cars equipped with four-wheel ABS almost completely offsets the safety advantage such vehicles have over their conventionally-braked counterparts. The National Highway Traffic Safety Administration (NHTSA) has developed its Light Vehicle Antilock Brake Systems (ABS) Research Program in an effort to determine the cause(s) of the apparent increase in fatal single-vehicle run-off-road crashes as vehicles undergo a transition from conventional brakes to ABS. As part of this program, NHTSA conducted research examining driver crash avoidance behavior and the effects of ABS on drivers' ability to avoid a collision in a crash-imminent situation. The study described here was conducted on a test track under dry and wet pavement conditions to examine the effects of ABS versus conventional brakes, ABS brake pedal feedback level, and ABS instruction on driver behavior and crash avoidance performance. This study found that drivers do tend to brake and steer in realistic crash avoidance situations and that excessive steering can occur. However, a significant number of road departures did not result from this behavior for either pavement condition. ABS was found to reduce crashes significantly on wet pavement as compared to conventional brakes.

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EXECUTIVE SUMMARY

In 1997, NHTSA initiated a three-year Light Vehicle ABS Research Program to examine all plausible reasons why crash data studies had not shown that ABS had improved automobile safety by producing a net reduction in fatal crashes. In fact, ABS was associated with a statistically significant increase in the frequency of single-vehicle, run-off-road (rollovers or impacts with fixed objects) fatal crashes, as compared to cars without ABS. One hypothesis for this phenomenon was based on the idea that, if drivers tend to "oversteer" during a crash avoidance maneuver, ABS may give them the ability to steer their vehicles off-road in cases in which a vehicle equipped with conventional brakes would experience wheel lockup and skid in the direction of the vehicle's momentum with little directional control.

To investigate this hypothesis, an experiment was conducted in which drivers' collision avoidance behavior in a simulated right-side intersection incursion scenario was examined as a function of vehicle brake system (conventional, ABS) and pavement condition (dry, wet). A crash avoidance scenario was staged in which a stopped vehicle would suddenly move across the path of a subject vehicle at an intersection causing the subject to take some evasive action to avoid colliding with the incursion vehicle. This scenario was run with a large number of subjects under both dry and wet pavement conditions to examine drivers' behavior in a crash-imminent situation and evaluate their crash avoidance performance with ABS versus conventional brakes. In addition to brake system and pavement condition, independent variables examined included time-to-intersection, ABS brake pedal feedback level, gender, and the effects of ABS instruction and braking practice.

Results of this study found that nearly all subjects both braked and steered during their crash avoidance maneuvers. In fact, subjects in these studies demonstrated the capability to make aggressive steering and braking inputs. Some evidence of driver oversteering was seen. However, despite the high magnitudes and rates of many steering inputs observed, very few road departures occurred. Those road departures that were observed could not be judged attributable to ABS performance nor driver interaction with ABS. Although these data suggest that oversteering with ABS may not be responsible for the increase in single-vehicle road departure crashes, it is not clear whether the extent to which oversteering was seen in this study is comparable in proportion to that associated with the road departure crash trend phenomenon.

ABS was found to have beneficial effects on crash rates for some conditions in this research. On wet pavement, 97 percent of subjects activated ABS in the intersection incursion scenario. ABS was associated with significantly fewer crashes on wet pavement as compared to conventional brakes.

With no ABS instruction or braking practice, subjects in the ABS condition crashed 50% less than those in the conventional brake system condition on wet pavement. No significant reduction in crashes was seen on dry pavement for ABS versus conventional brakes regardless of training provided. Providing subjects with video instruction on the proper use of ABS did not produce a significant reduction in crashes for either pavement condition. For subjects in the dry pavement study who received braking practice prior to the incursion event, those with ABS crashed half as much as those with conventional brakes. Although providing ABS instruction did not reduce crashes in this research, there was evidence that ABS instruction may reinforce proper braking techniques.

Heavy ABS brake pedal feedback was associated with fewer crashes on wet pavement than was light ABS brake pedal feedback, however, not at a significant level. No evidence of subjects being startled by ABS brake pedal feedback and removing their foot from the brake pedal was seen in this research.

In conclusion, the results of this study do not appear to indicate that a problem exists due to driver crash avoidance behavior or driver interaction with ABS that would contribute to the apparent increase in fatal single-vehicle crashes as identified in conjunction with vehicles transitioning from conventional to antilock brake systems. Results from this study will be examined in conjunction with the results of other tasks included in NHTSA's Light Vehicle ABS Research Program to determine whether the collective results viewed as a whole provide some insight into the cause of the increase in fatal single-vehicle crashes observed in conjunction with the implementation of ABS.

The authors acknowledge that these results are specific to the particular intersection incursion scenario used in this study. The results may not apply to other types of crash avoidance scenarios. In addition, the authors feel testing of this sort involving higher travel speeds (greater than 45 mph on dry and 35 mph on wet pavement) should be investigated. Additional insight may be obtained by conducting similar research using different crash avoidance scenarios and vehicle travel speeds.

1.0 INTRODUCTION to the NHTSA LIGHT VEHICLE ABS RESEARCH PROGRAM

Since 1985, antilock brake systems (ABS) have been increasingly available on many passenger car and light truck make/models. ABS has been sold in four-wheel and two-wheel versions, with four-wheel ABS being found primarily on passenger cars and two-wheel ABS being prevalent on light trucks. These systems have been marketed as an added safety feature designed to enhance drivers' ability to control a vehicle.

With the introduction of ABS, the National Highway Traffic Safety Administration (NHTSA) undertook a series of investigations to determine the potential benefits of ABS and the effect of ABS on crash rates. Test programs have shown that these systems appear to be very promising safety devices when evaluated on a test track. Under many braking conditions on paved surfaces, four-wheel ABS allows the driver to stop a vehicle more rapidly than with conventional brakes while maintaining steering control even during situations of extreme, panic braking. Brake experts anticipated that the introduction of ABS on passenger vehicles would reduce both the number and severity of crashes. However, a number of crash data analyses have been performed in recent years by NHTSA, automotive manufacturers, and others which have shown for passenger cars that the introduction of ABS has not been associated with a net reduction in crashes to the expected extent.

1.1. CRASH DATA

Kahane [1] found that, for passenger cars, involvements in multi-vehicle crashes on wet roads were significantly reduced for cars equipped with ABS: fatal crashes were reduced by 24 percent, and nonfatal crashes by 14 percent. A significant 27 percent decrease in fatal collisions with pedestrians and bicyclists was also found to be associated with ABS. However, these reductions were offset by a statistically significant increase in the frequency of single-vehicle, run-off-road crashes, as compared to cars without ABS. Run-off-road crashes, as considered in this report, included rollovers, side impacts with fixed objects, and frontal impacts with fixed objects. Fatal run-off-road crashes were up by 28 percent and nonfatal crashes by 19 percent with ABS. On wet roads, fatal run-off-road crashes increased 17 percent and non-fatal run-off-road crashes increased by 24 percent. On dry roads, fatal run-off-road crashes increased by 29 percent while non-fatal crashes increased by 17 percent. It is unknown to what extent, if any, this increase is due to ABS or other causes. It is also unknown to what extent, if any, this increase is due to drivers incorrect usage of ABS or incorrect responses by drivers to their ABS.

Hertz, Hilton, and Johnson [2] presented results for passenger car run-off-road crashes according to the following crash types: rollovers, side impacts with parked vehicles or fixed objects, and frontal impacts with parked vehicles or fixed objects. For dry roads, ABS was found to be associated with a 17 percent decrease in all rollover crashes, a 13 percent decrease in all frontal impacts with parked vehicles or fixed objects, and a 7 percent increase in all side impacts with parked cars or fixed objects. For all pedestrian crashes, ABS was associated with a 30 percent reduction on dry roads and a 10 percent reduction in unfavorable road conditions (i.e., wet, snowy, icy, gravel). In regards to only those crashes involving fatalities, ABS was found to be associated with a 51 percent increase in fatal rollover crashes on dry roads. For fatal side impact crashes, ABS produced a 69 percent increase for unfavorable road conditions, and a 61 percent increase for favorable road conditions. ABS was associated with a 38 percent decrease in fatal pedestrian crashes in unfavorable road conditions. Fatal frontal impact crashes in unfavorable road conditions were also decreased by 40 percent with the introduction of ABS.

In comparison, some benefits were observed for light vehicles other than automobiles (pickup trucks, sport utility vehicles, and vans), equipped with two-wheel ABS (instead of the four-wheel ABS used on automobiles). Rear-wheel antilock brake systems have been effective in reducing the risk of nonfatal run-off-road crashes for almost every type of light truck [3]. Nonfatal rollovers were reduced by 30 to 40 percent. Side impacts with fixed objects were reduced by 15 to 30 percent. Frontal impacts with fixed objects were reduced by 5 to 20 percent.

1.2. NHTSA'S LIGHT VEHICLE ABS RESEARCH PROGRAM

In an effort to investigate possible causes of the crash rate phenomena identified, NHTSA developed its Light Vehicle ABS Research Program. This program contained nine separate tasks which address potential theories as to the cause of the lack of net crash benefits such as driver behavior in a crash-imminent situation, driver response to ABS activation, ABS hardware performance, and environmental factors (as outlined in [7]). To date, NHTSA research has found no systematic hardware deficiencies in its examination of ABS hardware performance (as documented in [8]). It is unknown, however, to what extent the increase in run-off-road crashes may be due to drivers' incorrect usage of ABS, incorrect response to ABS activation, incorrect instinctive driver response (e.g., oversteering), changes in driver behavior (i.e., behavioral adaptation) as a result of ABS use, and/or some other factor.

Task 1 of NHTSA's Light Vehicle ABS Research Program, performed by Hertz in 2000 [5] as mentioned in the previous section, involved performing a new crash data study of the effect on safety of adding four-wheel ABS to automobiles. This study differed from those previously conducted [1, 2, 3, 4] in that it focused on newer vehicles and antilock brake systems and included some methodological improvements. This study endeavored to address whether whatever problem may have caused the apparent increase in single-vehicle crashes for ABS-equipped automobiles still existed following the introduction of newer generation ABS hardware.

Task 2 [9] of this program involved conducting a national telephone survey to determine drivers' knowledge and expectations about ABS. The purpose of this 1998 survey was to assess whether the apparent increase in single-vehicle crashes for automobiles might be due to drivers' misunderstanding of ABS functionality. Results of the survey showed that, although most drivers had heard of ABS, many did not know what it did or how it affected vehicle performance, when it functioned, or even if their vehicle was so equipped. Certain types of brake pedal feedback from an activated ABS were often misinterpreted, making driver reaction inappropriate and in some cases potentially dangerous. There was also some evidence drivers of ABS-equipped vehicles placed more confidence in ABS and what it could do for them than the non-ABS owners did. Lastly, this survey also found that information imparted at the time of purchase was the means by which the majority of drivers find out about the brakes on their vehicle. However, approval ratings for lengthy or mandatory information sessions were not well received, though some methods held promise.

Task 3 involved the examination of 257 selected single-vehicle 1996 crash reports collected by the National Automotive Sampling System (NASS). The goal of this work was to determine what differences could be identified in the characteristics of single-vehicle crashes incurred by ABS-equipped versus non-ABS-equipped automobiles using NASS Crashworthiness Data System (CDS) cases. Results of this examination of crash cases did not provide conclusive evidence that ABS had a significant effect on crash rates for the time period covered.

Task 4 [8] measured the braking performance of a group of model year 1993-97 production ABS-equipped vehicles over a broad range of surfaces and maneuvers. While ABS stopping performance has been measured by many groups over many years, there is a possibility that poor performance on some unusual surface or during some maneuver may have been overlooked. If such could be found, this might explain the apparent increase in single-vehicle crashes of ABS-equipped automobiles. Results of this 1997-98 study showed that for most maneuvers, on most surfaces, ABS-assisted stops yielded distances shorter than those made with the ABS disabled. The one exception was on loose gravel where stopping distances increased by an average of 27.2 percent overall. Additionally, the vehicular stability observed during testing was almost always superior with ABS. For the cases in which instability was observed, ABS was not deemed responsible for its occurrence.

Task 5 examined the hypothesis that the apparent increase in single-vehicle crashes with ABS-equipped vehicles is due to driver "oversteering" in crash-imminent situations. In a crash imminent situation, a driver's first action is expected to be a very hard application of the brake pedal. Oversteering occurs when the driver, possibly believing that the hard braking input is insufficient to avoid the upcoming obstacle (such as another vehicle), rapidly turns the steering wheel by a large amount. For conventionally braked or rear-wheel ABS only vehicles, this oversteering has little effect, since the initial driver brake pedal activation is likely to lock the vehicle's front wheels. However, for a vehicle equipped with four-wheel ABS (where the ABS minimizes front wheel lockup and allows the driver to maintain steering capability), the oversteering may result in the vehicle missing the upcoming obstacle, going off of the roadway, and being involved in a single-vehicle crash.

Task 5 was divided into multiple subtasks to examine driver crash avoidance behavior with and without ABS. This task sought to assess the prevalence of driver oversteering and examined the effects of ABS instruction and braking practice on successfully avoiding a crash. Task 5.1 used a driving simulator to address this issue. Task 5.2 examined driver crash avoidance behavior in a test track environment on a dry, high coefficient of friction road surface. Task 5.3 also studied driver crash avoidance behavior in a test track environment but on a wet, low coefficient of friction road surface. Results of the 1997-98 test track studies, Tasks 5.2 and 5.3 [10], showed that drivers do tend to brake and steer in realistic crash avoidance situations and that excessive steering can occur. However, a significant number of road departures did not result from this behavior for dry or wet pavement. ABS was found to significantly reduce crashes on wet pavement as compared to conventional brakes. Results of the 1997 simulator study (Task 5.1) [11] also showed that excessive steering can occur during realistic crash avoidance situations. However, this steering was not found to result in a significant number of road departures.

In 2000, Task 6 investigated the effects of ABS during road recovery maneuvers (i.e., when a driver attempts to maneuver an automobile back onto the roadway after a departure). Many road departures occur when the driver drives the vehicle in an essentially straight line that leaves the road. This action may be due to driver inattention, sleepiness, or intoxication. None of these causes are related to the presence or absence of ABS. However, the presence of ABS may or may not influence the ability of the driver to safely maneuver the vehicle back onto the roadway.

Task 7 involved two separate studies that examined the issue of ABS and behavioral adaptation. Several studies have found that people drive faster or more aggressively on test tracks in ABS-equipped vehicles than with conventionally braked vehicles. The goal of this task was to try to determine if these trends occur during typical driving on actual public roads.

Task 7 was divided into multiple subtasks. Task 7.1 [12] involved remote, unobtrusive observation methods to collect data about the behavior (e.g., speed) of drivers. Although a consistent trend was seen in mean speed by brake system for each site with slightly higher speeds being observed for drivers of ABS-equipped vehicles, this trend was not statistically significant. This study showed that type of brake system (ABS or conventional) had no significant effect on driving speed under the conditions examined. Task 7.2, the subject of this report, sough to assess possible ABS-related behavioral adaptation through the collection of more detailed data about the driving behavior of a small number of subjects using instrumented vehicles in a naturalistic research setting.

Task 8 involved the integration of data from all of the preceding tasks in an attempt to infer why the crash data studies did not find the anticipated increase in safety for ABS-equipped automobiles.

Task 9 involved the dissemination of task results. NHTSA has shared knowledge gained through the program's research efforts by reporting its findings with interested parties within NHTSA and the public at large. Summaries of current research efforts and results-to-date have been presented for discussion.

NHTSA's Light Vehicle ABS Research Program has only been a first step in assessing the anticipated safety benefits from ABS. This program deals solely with trying to learn why the crash data studies did not find the anticipated increase in safety (i.e., reduction in crashes) for ABS-equipped automobiles. The development of countermeasures to resolve any problems discovered is left to future research.

1.3. INTENT OF THE RESEARCH PROGRAM

NHTSA's Light Vehicle ABS Research Program is only a first step in assessing the anticipated safety benefits from ABS. This program deals solely with trying to learn why the crash data studies did not find the anticipated increase in safety for ABS-equipped automobiles. The development of countermeasures to resolve any problems discovered is left to future research.

1.4. TASK 5: DRIVER CRASH AVOIDANCE BEHAVIOR USING CONVENTIONAL AND ANTILOCK BRAKES – BACKGROUND AND PURPOSE

To determine whether some aspect of driver behavior in a crash-imminent situation may be counteracting the potential benefits of ABS, NHTSA embarked on a series of human factors studies. These studies, which compose Task 5 of the research program, focus on the examination of driver crash avoidance behavior as a function of brake system and various other factors.

One theory, which Task 5 sought to address, was whether the apparent increase in fatal single-vehicle crashes involving ABS-equipped vehicles may be due to characteristics of driver steering and braking behavior in crash-imminent situations. According to this theory, in situations of extreme, panic braking, drivers may have a tendency to brake hard and make large, potentially excessive, steering inputs in an attempt to avoid a crash.

In a crash-imminent situation, a driver's initial reaction may be either to steer or release the throttle. If a driver steers as the initial reaction, the secondary response may be to release the throttle and then apply the brakes (third response). In rare circumstances, a driver may steer initially, release the throttle, and then never apply the brakes. If the driver releases the throttle as the initial reaction, the secondary response may be to either brake or steer. If a driver then steers as the secondary response after having released the throttle, the third response may be to apply the brakes; likewise, if the secondary response was to brake, the third response may be to steer. Depending on which combination of reaction possibilities the driver exercises, the implications of oversteering occurring may be more or less severe.

If the driver brakes hard and steers, oversteering may occur when the driver, possibly believing that the hard braking input will be insufficient to avoid the obstacle, rapidly turns the steering wheel by a large amount. For conventionally braked or rear-wheel ABS vehicles, aggressive braking may lock the front wheels of the vehicle, eliminating directional control capability, rendering the driver's steering behavior irrelevant. However, with four-wheel ABS, wheel lockup is minimized. As a result, the vehicle does not lose directional control capability during hard braking and driver's steering inputs are then effective in directing the vehicle's motion. This directional control could result in drivers avoiding multi-vehicle crashes by driving off the road and, instead, experiencing single-vehicle crashes.

To investigate this theory, Task 5 sought to address issues such as whether:

- Drivers tend to both brake and steer (as opposed to only braking or only steering) during crash avoidance maneuvers;
- Drivers tend to make large, potentially excessive, steering inputs during crash avoidance maneuvers;

- Drivers' crash avoidance maneuvers in ABS-equipped vehicles result in road departures more often than in vehicles with conventional brakes; and
- Drivers avoid more crashes in ABS-equipped vehicles than in vehicles with conventional brakes.

Task 5 of NHTSA's Light Vehicle ABS Research Program includes three studies. Two studies were conducted on a test track (one on dry pavement, Task 5.2; and one on wet pavement, Task 5.3) and one on the University of Iowa's Iowa Driving Simulator (IDS) (Task 5.1).

These studies used a right-side intersection incursion scenario to elicit a crash avoidance response from human subjects. This scenario was chosen because it was likely to induce steering behavior and had the potential for subjects driving the vehicle off of the road. This obstacle avoidance scenario is not responsible for all, or even most, run-off-road crashes and results may not be representative of driver behavior in all situations leading to vehicle road departure. Many run-off-road crashes occur when drivers are unable to maneuver through a curve in the roadway or when they are drowsy or under the influence of alcohol. However, it is believed that the results of this study will be useful in determining not only the extent to which drivers are able to maneuver a vehicle, but also drivers' physical capacity to supply control inputs to the vehicle. Insight into drivers' ability to maintain vehicle control during a panic maneuver and ability to avoid a collision can also be gained from this research.

Although the same intersection incursion scenario was involved in each of these experiments, each experimental venue provided unique advantages for observing driver behavior. The test track experiments allowed driver behavior to be examined in a realistic environment at moderate speeds in real vehicles with simulated obstacles on both dry and wet pavement. The IDS study allowed for driver behavior to be examined using a highly repeatable test method in a simulated environment at higher travel speeds and with no chance of actual physical collision or injury.

The fundamental knowledge gained through these tests will aid researchers in assessing the extent of drivers' abilities in crash imminent situations. Through this assessment of driver behavior with both conventional and antilock brakes, researchers will be able to infer whether ABS enhances drivers' collision avoidance capabilities over those attainable with conventional brakes without increasing the probability of roadway departure. This final report discusses the methods used and results obtained from both the dry and wet pavement test track studies and attempts to address these issues.

2.0 RELATED RESEARCH

This study was not the first to examine driver behavior in an obstacle avoidance scenario. The following are descriptions of studies of driver behavior in crash-imminent situations including one study involving ABS.

2.1. DRIVING SIMULATOR STUDY OF EMERGENCY BEHAVIOR

A previous NHTSA study [7,8] performed under Contract No. NRD-20-95-08086 on the Iowa Driving Simulator (IDS) utilized a crash scenario which was very similar to the one employed in this research. The IDS study was conducted to examine the collision avoidance behavior and reaction time to an unexpected intersection incursion while driving a vehicle equipped with conventional brakes only, since at the time the IDS did not have the capability to simulate ABS. This study involved an intersection incursion, which occurred at the intersection of two, two-lane rural highways. Traffic on the crossing road was controlled by stop signs, while the roadway on which the subject was traveling had no traffic signals and thus had the right of way through the intersection. The speed limit on this roadway was 55 mph. At one of three possible time-to-intersection (TTI) values an incursion vehicle began moving into the intersection in front of the subject vehicle. The incursion vehicle could intersect from either the driver's left or right side, and either completely blocked the driver's lane or blocked one-half of the driver's lane.

The principle results of the IDS study indicate drivers are most successful at avoiding an incursion vehicle when the escape gap is large and/or the required steering magnitude is small. Drivers appear to use this information, along with the time-to-intersection in the formulation of an avoidance strategy. The study demonstrated that drivers have more difficulty avoiding an incursion vehicle when it intrudes into the driver's lane from the left than from the right.

During a severe obstacle avoidance maneuver, drivers will often lock the brakes and attempt to steer (with the brakes locked). Drivers may input large amplitude steering movements, or "oversteer", in emergency avoidance situations. With conventional brakes locked (the vehicle in a longitudinal skid with minimal lateral control), the oversteering does no harm. However, for an ABS-equipped vehicle, a large amplitude steering input is likely to increase the chance of lateral skidding, roadway departures, and subsequent roll-over crashes. In this study, more than 80% of subjects in this study locked wheels when attempting to avoid the incursion vehicle. Over 70% of subjects attempted to steer when the wheels were locked. Over 80% of the subjects who attempted to steer when wheels were locked collided with the incursion vehicle. Thus, it appears that the hypothesis that drivers tend to exhibit instinctive steering inputs of significant magnitudes in panic situations is a plausible one and that ABS, by allowing the vehicle's wheels to continue to roll during aggressive braking, may be allowing drivers to maneuver their vehicles into potentially dangerous off-road situations.

2.2. OTHER RELEVANT STUDIES

Several field studies in which an object was projected into the subject vehicle's path have been performed to examine drivers' obstacle avoidance behavior. The method has been successfully used to investigate driver reaction times and behavior in response to an incursion obstacle. The following are brief summaries of three such studies.

2.2.1. Prynne, K. and Martin, P.: *Braking Behavior in Emergencies* (1995)

This study [10], performed by Lucas Industries, endeavored to determine in what way, if any, a typical driver's emergency braking behavior was inadequate. The experiment created an unexpected, sudden, obstacle avoidance situation so as to generate driver panic braking behavior.

Seventy-seven subjects were recruited. Subjects were characterized by gender, age, and level of driving experience. Tests were initially conducted using a polystyrene obstacle that was propelled into the path of the subject vehicle. The polystyrene obstacle did not, however, elicit a sufficiently authentic crash avoidance response from the drivers and was eventually replaced with life-size painted figures representing children running out into the road. These child-like obstacles were judged to be successful in achieving a higher degree of realism. The life-size painted figures proved to be realistic enough to elicit a genuine crash avoidance response from subjects but not so life-like that the subjects feared that they were facing a potential collision with an actual child.

This study found that drivers typically exhibit a two-stage braking behavior in response to potential frontal crash conflicts. Most subjects initially applied the brake moderately and then hesitated momentarily, holding the brake pedal steady at a moderate application level. Then, when subjects perceived the threat could not be avoided by a moderate brake application and required an all-out avoidance response, they continued their brake application to achieve full brake application. For tests involving the child-like obstacles, 66 of the 77 subjects demonstrated a pause or break in their brake application. Fifteen subjects collided with the obstacles.

Prynne, et al. attempted to create a realistic driving event by projecting obstacles in the path of unprepared drivers. In this regard, the study is very similar to that used in Task 5 of NHTSA's Light Vehicle ABS Research Program. Unfortunately, even the detail of the painted figures was unable to convince the subjects the event was truly realistic for an adequate time period. Subjects regarded the painted figures as very realistic at first glance, but quickly realized the true nature of these obstacles. The realism of the obstacles was sufficient enough, however, that the scenario elicited authentic collision avoidance responses from subjects. The Task 5 research addressed this shortcoming by increasing the level of detail of the obstacle using a full-scale photograph of an automobile adhered to a polystyrene cutout.

2.2.2. Lerner, N.D.: Brake Perception-Reaction Times of Older and Younger Drivers (1993)

This study [11] was performed by the COMSIS Corporation. The experiment attempted to establish whether current perception-reaction time values used in highway design applications adequately meet the requirements of older drivers during braking situations.

This experiment involved 116 subjects divided into three age groups. To increase the validity of the results, each of the subjects drove their own vehicle while participating in the study. Subjects were instructed to drive on an isolated stretch of roadway. When a subject reached a location near the midpoint of the roadway section, a large yellow crash barrel, hidden on a berm behind some brush, was remotely released and suddenly became visible rolling toward the roadway. Although it appeared to be rolling directly into the road, a set of chains held the barrel to the shoulder area and prevented it from actually entering the roadway. The barrel emerged into view approximately 200 feet in front of the vehicle, providing a time-to-collision of about 3.4 s at the target speed of 40 mph.

Eighty-seven percent of the 116 drivers performed some form of vehicular maneuver in response to the emergence of the barrel. The mean brake perception-reaction time for all subjects was 1.5 s, with no significant effect due to either age or gender. The 2.5 s value used for perception-reaction time in highway design applications was thus deemed to provide adequate coverage for the full range of driver age.

Lerner attempted to create a real world situation by testing drivers in their own vehicles, driving on actual roads, under conditions in which they were not expecting any unusual events. The barrels utilized in this study evoked collision avoidance responses from most drivers, however, these maneuvers may not be indicative of those used by drivers when a more realistic road hazard (such as an incursion vehicle) is utilized.

No reference was made to any subject experiencing physical or psychological trauma resulting from participation in this study.

2.2.3. Priez, A., Petit, C., Guezard, B., Boulommier, L., Dittmar, A., Delhomme, A., Vernet-Maury, E., Pailhous, E., Foret-Bruno, J., Tarriere, C.: How about the average driver in a critical situation? Can he really be helped by primary safety improvement? (1991)

Similar to the Prynne and Martin study previously outlined, experiments performed by Renault [12] also employed a controlled, encroaching obstacle in an effort to observe driver crash avoidance behavior. Tests were performed to examine driver performance in a crash imminent situation as a function of ABS knowledge and training.

One hundred volunteer subjects were recruited including both male and female drivers. Subjects were grouped according to age, length of time in possession of a driver's license, emotionality (ability to react to a stressful situation), and reaction speed to an unexpected event. Subjects completed three practice runs to become familiar with the car and the course, and four runs for the testing session. On the final run of the testing session, an inflatable car having the same features of cars previously parked on the course was released into the last intersection. To successfully avoid collision with the inflatable car, subjects had to steer and brake simultaneously.

Based on the results for 87 subjects, 80% of the drivers given ABS training either successfully avoided or tried to avoid the obstacle compared to only 40-50% of subjects in the three other groups that did not receive training. Of the subjects who received ABS training and who drove vehicles equipped with ABS, 29.2% were able to avoid the obstacle.

The use of a large inflatable obstacle in this study represented an attempt to test subjects' reactions to a realistic three-dimensional automobile-like obstacle. However, upon review of test runs from this study on videotape the detail of this vehicle was still found to be quite crude. Few subjects were convinced the inflatable car was real, however its approximately life-size dimensions may have presented the subject with a sight intimidating enough to elicit authentic driver crash avoidance behavior. Fabrication of a more detailed inflatable car for use in the proposed study was investigated, however the costs involved were much too high.

Priez et al. made no reference to any subject experiencing physical or psychological trauma resulting from participation. The inflatable vehicle was designed with a panel that opened upon impact, thus diminishing the forces of the collision. The only reference made to the subjects' emotional state was the surprise exhibited by those who could not avoid the obstacle when they were informed that others had successfully avoided it.

2.3. COMMENTS ON RELATED RESEARCH

The above studies demonstrate that the use of a propelled obstacle to elicit driver crash avoidance behavior is both a feasible and valid research method. These studies were performed safely and the use of the obstacles did not cause harm to the test vehicles or the subjects. No physical or psychological harm was detected in any of the test subjects following their participation. The use of an automobile-like polystyrene obstacle, as used in Task 5, also allows the acquisition of valid data to describe driver emergency obstacle avoidance behavior while maintaining the safety of subjects and preventing collision damage costs to the test vehicles.

3.0 METHOD

3.1. SUBJECTS

For these studies, a total of 245 subjects from the central Ohio area were tested. In order to complete these studies in an economical manner and within the required time frame of the research program, fewer subjects were involved in the wet pavement study than in the dry pavement study. The number of subjects participating in the dry pavement study was 192 while in the wet pavement study there were 53 subjects.

3.1.1. Solicitation of Participants

Subjects were solicited using newspaper advertisements (see Appendix A) and flyers (see Appendix B). Persons responded to the advertisements via telephone. Potential subjects were asked a series of questions relating to their health and driving habits to ensure that they were fit to participate and were given a brief description of what their participation would entail.

3.1.2. Subject Characteristics and Selection Criteria

Subjects recruited were between 25 and 55 years of age. Eligible candidates had no major medical problems that would adversely affect driving ability and were able to drive an automatic transmission vehicle without assistive devices or special equipment. The number of males and females per experimental condition was approximately balanced. All subjects were pre-screened to ensure they had a valid Ohio driver's license, no convictions for driving under the influence (DUI) within the previous five years, and had driven at least 3000 miles in the previous year.

Subjects who were accepted for participation were ones who reported that they did not use a vehicle equipped with ABS as their primary mode of transportation. In addition, subjects may have driven an ABS-equipped vehicle before, but had never personally activated ABS. The selection of persons who had never before experienced ABS activation would permit the assessment of the degree to which drivers tend to get startled by ABS brake pedal feedback.

Subjects were recruited without regard for their occupation and were assumed to be representative of the population of average drivers dwelling in the central Ohio area. A subsequent examination of subject demographics showed that, in the dry pavement study, 7 percent were professional truck drivers and as many as 4 percent of subjects held some other occupation that involved driving as part of their job duties. Likewise, approximately 2 percent of subjects (1 subject) in the wet pavement study were reported to be truck drivers and another approximately 2 percent (1 subject) had another occupation that involved driving.

Subjects were required to sign an informed consent statement and agree that NHTSA shall have unrestricted use of the videotape, containing views of their face, and engineering data associated with the videotape. Subjects were also required to agree that NHTSA may disseminate the images contained on the videotape for education, outreach, and research purposes, in perpetuity.

3.1.3. Subject Pay

Subjects were compensated in the amount of $50 for their participation in this experiment that required approximately ninety minutes of their time.

3.2. PILOT TESTING FOR SCENARIO REFINEMENT

Pilot testing was conducted prior to the dry pavement test to determine and refine the details of the incursion implementation and also to determine and confirm the "Time-To-Intersection" values to be used. These values were determined with a focus on the dry pavement testing since, at the time, no wet pavement testing was planned. Subsequently, values selected for the dry pavement study were found to be feasible for implementation on wet pavement. Pilot test subjects were not counted as part of the 245 overall subjects tested in this research.

3.2.1. Time-To-Intersection (TTI) Value Determination

Time-To-Intersection (TTI) was defined as the time it would take the subject vehicle to reach the intersection at its current velocity as measured at a defined "trigger" point in the roadway. The timing of the start of the incursion vehicle's motion was controlled using one of two values of TTI. This allowed for the examination of differences in drivers' reactions as a function of time available to respond to the event.

Candidate TTI values were selected to promote driver steering and to represent two conditions: one in which most but not all drivers would be able to avoid a collision with conventional brakes, and one in which only very few drivers could avoid a crash with conventional brakes. Pilot testing was conducted using TTI values ranging from a minimum of 2.5 seconds to a maximum of 4.5 seconds. Values used in the previous IDS study [7,8] were also included. Results of the pilot test showed that the values of 2.5 and 3.0 seconds were likely to produce the desired response and scenario outcomes as described above. As a result, these values were incorporated in the experimental design, which is outlined in section 3.3 of this report.

3.2.2. Incursion Level and Direction

To control cost and minimize the complexity of test conduct, it was decided that either a left side incursion or right side incursion, but not both, would be implemented in the study. Based on the results of a previous study conducted on the Iowa Driving Simulator [7,8], only a right side incursion was selected for use in these studies.

Initial pilot testing involved both full incursions and partial incursions. A full incursion involved the simulated vehicle pulling out in front of the subject vehicle and coming to rest centered in the subject vehicle's 12 foot (3.7 m) lane of travel. For a partial incursion, the simulated vehicle would stop 6 feet (1.8 m) into the subject vehicle's lane of travel, thus blocking half of the lane. Based on the results of the pilot testing, the results of the previous IDS study [7], and to control cost, only a partial incursion from the right side was used rather than both full and partial incursions.

3.3. EXPERIMENTAL DESIGN

The experimental design for these studies included the following seven independent variables:

- Brake system
- ABS brake pedal feedback level
- Test vehicle
- ABS instruction
- Braking practice (not included in wet pavement study)

- TTI
- Gender

In addition, the composite experimental design shown in Table 1 represents "pavement condition" as an eighth independent variable (although it was not the initial intent to conduct this testing under multiple surface conditions). Pavement condition is inherently tied to speed limit since the dry pavement testing was conducted at 45 mph (72 kph) only and the wet pavement testing at 35 mph (56 kph) only. The subset of independent variables common to both the wet and dry pavement studies included brake system (ABS, conventional brakes), ABS brake pedal feedback level (light, heavy), ABS instruction, and gender.

The dry pavement test involved 8 subjects per condition for a total of 192. The wet pavement test involved 9 participants per condition (except for one condition in which there were only 8 participants). The order of presentation of conditions was randomized for both tests by individual repetitions of the test matrix. Gender was approximately balanced per experimental condition.

3.3.1. Brake System

Participants were divided between a conventional brake system condition and an ABS condition. To create the conventional brake system condition, the ABS was electronically disabled.

3.3.2. ABS Brake Pedal Feedback Level

ABS was further broken down by brake pedal feedback level. ABS brake pedal feedback was defined as the degree of vibration present in the brake pedal during ABS activation. Two levels of ABS brake pedal feedback were used, light feedback and heavy feedback.

3.3.3. Test Vehicles

The use of two test vehicles was required in order to obtain the two ABS brake pedal feedback levels. A maroon-colored 1995 Chevrolet Lumina equipped with a Delco VI ABS represented the light feedback condition. A green 1996 Ford Taurus equipped with a Bosch ABS represented the heavy ABS brake pedal feedback condition. In order to account for any potential vehicle effects, both vehicles were also tested in the conventional case. This results in the secondary independent variable, vehicle, which was examined to identify any potential confounding effects of vehicle make/model.

Table 1. Experimental Design for Main Test (shaded cells represent conditions not tested)

			DRY PAVEMENT (45 mph, 72 kph)				WET PAVEMENT (35 mph, 56 kph)			
			Conventional Brakes		ABS		Conventional Brakes		ABS	
					Light ABS Brake Pedal Feedback	Heavy ABS Brake Pedal Feedback			Light ABS Brake Pedal Feedback	Heavy ABS Brake Pedal Feedback
Time-To-Intersection (TTI)	ABS Instruction	Braking Practice	1995 Chevrolet Lumina	1996 Ford Taurus	1995 Chevrolet Lumina	1996 Ford Taurus	1995 Chevrolet Lumina	1996 Ford Taurus	1995 Chevrolet Lumina	1996 Ford Taurus
2.5 seconds	No Instruction	No Practice								
	Instruction	No Practice								
	No Instruction	Practice								
	Instruction	Practice								
3.0 seconds	No Instruction	No Practice								
	Instruction	No Practice								
	No Instruction	Practice								
	Instruction	Practice								

3.3.4. ABS Instruction

To address whether drivers may be more likely to crash in an ABS-equipped vehicle due to lack of knowledge about ABS, ABS instruction was included as an independent variable in these studies. ABS instruction consisted of a short video containing an initial segment describing the use of seat belts, air bag operation, and safety precautions, as well as a latter segment, which illustrated ABS operation and use. This ABS segment was taken from an OEM video [13] designed to be provided to new vehicle buyers to acquaint them with the features of their new vehicle. Of the subjects receiving the ABS condition, half received ABS instruction and the other half received no ABS instruction. Subjects in the conventional brake system condition were given no instruction other than the recorded audio instructions which all subjects received instructing them how to drive on the test route and test procedures.

3.3.5. Braking Practice

Braking practice was provided to half of the subjects in each of the two brake system conditions in the dry pavement study. Braking practice was only conducted in the dry pavement study since the location of the intersection in the wet pavement study was the same surface as that used for braking practice.

Before starting on the test route, subjects in the "braking practice" condition were given the opportunity to practice a braking maneuver involving obstacle avoidance on a wet Jennite-covered asphalt (low coefficient of friction) surface. Subjects were instructed by the in-vehicle experimenter to approach a coned lane at 35 mph (56 kph), drive through the lane maintaining that speed, and then at a certain point, brake and steer the vehicle as needed to avoid a traffic cone centered in the lane ahead. Subjects were not told exactly how to avoid hitting the cone, but were merely instructed to do whatever they felt was necessary and appropriate to do to avoid hitting it. Input provided to the subjects during this practice was constrained to a limited range of possible comments regarding their performance in order to prevent confounding of results by allowing variation of the level of oral instruction provided to subjects. Subjects repeated the maneuver two times for a total of three practice trials.

The purpose of this braking practice was to allow subjects in the ABS condition to experience the feel of ABS brake pedal feedback. The practice also allowed subjects to get a better feel for the braking and maneuvering capabilities of the test vehicle. In order to prevent confounding of the test results due to subjects in the ABS condition who received braking practice having more familiarity with the test vehicle due to experiencing the braking practice treatment, half of the subjects in the conventional brake system condition were also given braking practice. Thus exposure to the test vehicles and experience with braking practice was balanced across brake system conditions.

3.3.6. Time-To-Intersection

Time-To-Intersection (TTI) was defined as the time it would take a subject to reach the intersection at his or her current velocity as measured at a defined "trigger" point in the roadway. The purpose of this independent variable was to examine whether subjects altered their collision avoidance strategy based on the time available to respond to the event. Pilot testing was conducted prior to the main test to determine and confirm the TTI values to be used. These values were selected to promote driver steering and to represent two conditions: one in which most but not all drivers would be able to avoid a collision in a vehicle equipped with conventional brakes, and one in which only very few drivers could avoid a crash in a conventional brake system equipped vehicle. Due to difficulties with altering test equipment for accommodation of two TTI values, only one value (2.5 seconds) was used in the wet pavement study.

3.3.7. Speed Limit

For safety reasons, speed limits in the test track studies were kept to 45 mph (72 kph) on dry pavement and 35 mph (56 kph) on wet pavement. Results for the 45 mph (72 kph) condition can be compared to results for the Iowa Driving Simulator study [7,8] for the same speed.

3.3.8. Pavement Condition: Dry Versus Wet

The dry test track study was conducted on asphalt pavement having an approximate peak coefficient of friction of 0.9 and slide coefficient of 0.8. For the wet test track study, the simulated intersection was moved to a Jennite-paved pad, which was wetted for testing. This surface was the same as that used for braking practice in the dry pavement testing. The approximate peak coefficient of friction of the wet Jennite surface was 0.4; the approximate slide coefficient was 0.2.

3.4. INSTRUMENTATION

3.4.1. Sensor Data

The test vehicles were instrumented with the Data Acquisition System for Crash Avoidance Research (DASCAR). DASCAR is an unobtrusive data acquisition platform developed by NHTSA and Oak Ridge National Laboratory. This system monitors driver behavior and performance, vehicle performance, and their associations with the external environment [15]. The system was configured to record a variety of channels relating to parameters which described the dynamics of the vehicle as well as the subjects' vehicle control inputs. These parameters were sampled at 200 Hz and included displacement and rate of the steering inputs, force applied to the brake pedal, displacement of the throttle, vehicle ground speed, individual wheel speeds, traveled distance, and individual brake line pressures. A complete list of recorded sensor data channels for this study is provided in Table 2.

Table 2. Measured parameters (sensor data channels).

DATA CHANNELS	DEFINITION / MEANING	UNITS / VALUE
SunX	Trigger device on roadway to signify start of incursion event.	On / off
HW	Hand wheel angle.	Degrees
speed_EU	Vehicle speed.	Miles per hour
TPS	Throttle position sensor.	Volts
B_Light	Brake light indicator.	Volts
P1AMPF	Brake pedal force measured by load cell at left 1/3 of brake pedal.	Pounds
P2AMPF	Brake pedal force measured by load cell at center 1/3 of brake pedal.	Pounds
P3AMPF	Brake pedal force measured by load cell at right 1/3 of brake pedal.	Pounds
BrakeLP_LF	Line pressure going to the front left brake.	Pounds per square inch
BrakeLP_RF	Line pressure going to the front right brake.	Pounds per square inch
BrakeLP_LR	Line pressure going to the rear left brake.	Pounds per square inch
BrakeLP_RR	Line pressure going to the rear right brake.	Pounds per square inch
Wheelspd_LF	Speed of the left front wheel.	Miles per hour
Wheelspd_RF	Speed of the right front wheel.	Miles per hour
Wheelspd_LR	Speed of the left rear wheel.	Miles per hour
Wheelspd_RR	Speed of the right rear wheel.	Miles per hour
Roll_Rate	Roll rate of vehicle.	Degrees per second
Pitch_Rate	Pitch rate of vehicle.	Degrees per second
Yaw_Rate	Yaw rate of vehicle.	Degrees per second
Lat_Accel	Lateral acceleration.	g
Long_Accel	Longitudinal acceleration / deceleration.	g
Vert_Accel	Vertical acceleration.	g

3.4.2. Derived Parameters

Derived parameters for use in the data analysis were calculated from the measured sensor data channels. These derived parameters are listed in Table 3. Information regarding how each derived parameter was calculated is included in this table.

Table 3. Derived parameters.

PARAMETERS	DEFINITION / MEANING	UNITS / VALUE	CALCULATION
Brake pedal force	Total applied brake pedal force.	Pounds	Summation of instantaneous readings of the 3 load cells in the brake pedal.
ABS	On / off measurement of ABS activation.	On / off	
HW_Angle_Zero	Hand wheel angle zeroed from offset.	Degrees	Handwheel angle is collected with a relative encoder and derived into an absolute position.
HW_Rate	Hand wheel rate.	Degrees per second	Rate of change calculated from the handwheel position data.
Distance	Distance the vehicle traveled.	Feet	Integration of speed data.

3.4.3. Video Data

Video cameras were used to collect data both inside and outside of the vehicle. Within the vehicle, views were recorded to provide data on the subjects' eye glance behavior, steering inputs, driver hand position, and throttle and brake applications. A fourth view was used to record the forward road scene. These four views were multiplexed into one video signal using a quad-picture processor and simultaneously recorded in synchronization with the other measures collected. Figures 1 and 2 contain still-frame images of these video recordings. Additional full-frame video data were collected by two external sources. Frames include forward view in the upper left quadrant, driver's face in upper right, pedals in lower right, and over the shoulder in lower left. These views were captured from in front of (looking toward the intersection on approach) and behind (looking back at the intersection from beyond it) the intersection scenario to capture the motion of the test vehicle throughout the presentation of the obstacle avoidance scenario and preserve the scene on a full-frame video recording.

3.4.4. Safety Precautions During Testing

The test vehicles were also equipped with a pneumatic actuator that allowed the in-vehicle experimenter to bring the vehicle safely to a stop using the brake system. This provision was made to preserve safety in the event that a subject failed to follow the test procedures, exhibited dangerous behavior, or in the event of an emergency situation.

Figure 1. Quad-frame DASCAR video showing a subject approaching the simulated intersection prior to incursion.

Figure 2. Quad-frame DASCAR video showing a subject approaching the simulated intersection during the incursion.

3.5. TEST SCENARIO

In order to allow for the examination of driver behavior in an obstacle avoidance situation, it was necessary to select a scenario which would be both feasible and economical to implement on both a driving simulator and test track. A high level of test repeatability was also required in order to achieve accurate results. An intersection incursion scenario was chosen since it could be implemented in a realistic fashion using simulated vehicles.

3.5.1. Test Course and Simulated Intersection

Using 1995 National Automotive Sampling System (NASS) data, it was determined that single driver roadside departures most often occurred on dry, straight, and level asphalt roadways. Since the effects of ABS on braking performance differ based on pavement condition, testing was conducted both on dry and wet pavement to more completely investigate the hypothesized oversteering phenomenon.

To duplicate the desired road type, the Vehicle Dynamics Area (VDA) at the Transportation Research Center Inc. (TRC) in East Liberty, Ohio was used. The VDA is an 1800 foot x 1200 foot (548.6 m x 365.7 m), 50 acre (200,623 m^2) flat asphalt surface. This surface allowed sufficient space to lay out the simulated intersection without concern that the test vehicle could leave the paved test surface. The "figure eight" course on TRC's VDA was taken to simulate a realistic rural two-lane highway.

For dry pavement testing, the entire figure eight course was used. The dry testing was conducted on asphalt pavement having an approximate peak coefficient of friction of 0.9 and slide coefficient of 0.8. For this test, a simulated intersection (A) was integrated into a figure eight shaped course, as shown in Figure 3 [14]. All testing on dry pavement was completed prior to beginning the wet pavement testing.

For the wet pavement testing, only half of the figure eight course was used to allow the intersection to be located on the Jennite pad. This surface was the same as that used for braking practice in the dry pavement testing. In order to accommodate the different location of the intersection (B) for this pavement condition, an oval course was created by using only half of the figure eight course, also illustrated in Figure 3 [14]. The approximate peak coefficient of friction of the wet Jennite surface was 0.4; the approximate slide coefficient was 0.2.

The intersection used for both pavement conditions was created by applying reflective pavement marking tape to define the details of the crossing lane and the remaining intersection layout details. The dimensions and delineation of the intersection was determined according to Ohio Department of Transportation (ODOT) Office of Traffic Engineering (OTE) specifications appropriate for the type of roadway being simulated. The size and placement of stop lines [16], edge and center lines [17], and shoulder width [18] were determined using these specifications. The solid white stop lines were extended across each of the crossing lanes and were located 10 feet (3.1 m) from the edge of the perpendicular roadway, a distance which satisfied the ODOT OTE requirement stating that the stop lines should be placed no more than 30 feet (9.1 m) and no less than 4 feet (1.2 m) from the nearest edge of the intersecting roadway. To enhance the realism of the intersection, collapsible stop signs were used. These stop signs were located 6 feet (1.8 m) to the right of the stop lines.

To determine the appropriate shoulder width for the intersection's roads, the ODOT Office of Production "Rural Shoulder Criteria" were utilized. For a local road supporting traffic with over 400 automobiles per day and having a shoulder foreslope steeper than 6:1, a 6 foot (1.8 m) wide shoulder was required. The intersection roadway shoulders were therefore positioned 6 feet (1.83 m) from the roads' edge lines and outlined using 6 inch (15.2 cm) tall vinyl pylons spaced 20 feet (6.1 m) apart. These pylons were used to indicate where an unpaved surface might begin.

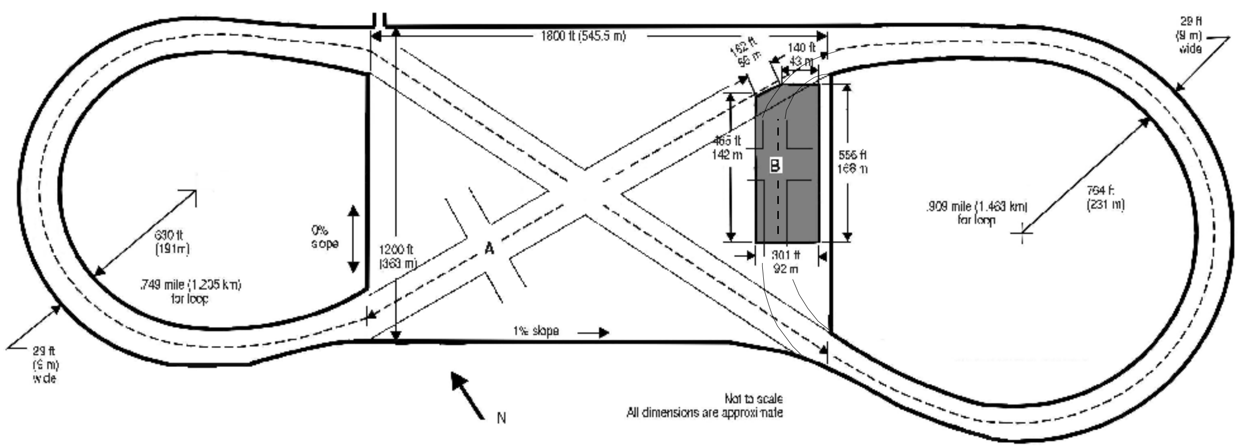

Figure 3. Illustration of location and layout of test courses used in the dry and wet pavement testing [14].

The road leading up to the intersection was straight for approximately 500 feet (152.4 m) before the intersection for the dry pavement condition. A short straightaway preceded the intersection in the wet pavement study. No oncoming traffic was present on the straight portions of the test course at any time. Vehicles unrelated to this test were kept away from the intersection at a distance sufficient to prevent conflict in the event of loss of control.

3.5.2. Test Obstacle

The simulated incursion vehicle was constructed from medium-density polystyrene foam. A life-size image of a 1992 Saturn SC was silk-screened onto the foam, and the silhouette of the vehicle cut out. When viewed from a distance (more than 100 ft) at an angle perpendicular to its length, as shown in Figure 4, the obstacle appeared to be an actual vehicle. The resolution of the silk-screen contributed to this realism, while the foam construction was intended to minimize damage to the test vehicles.

To enable the simulated vehicle to stand upright unassisted, a small truss constructed of polystyrene foam was used. This truss, which also provided additional rigidity to the vehicle without a significant increase in weight, extended approximately 3 feet (0.9 m) from the rear of the simulated vehicle and made contact with the ground at two points. To reduce friction, Teflon skid plates were used between the foam and the pavement. Figure 5 shows these features of the simulated incursion vehicle.

Figure 4. Front view of incursion vehicle.

Figure 5. Rear view of incursion vehicle showing truss support structure.

To ensure safety, a second polystyrene vehicle was constructed to emulate the actual silver Saturn used as the vehicle at the left side of the intersection. An identical truss was used for this simulated vehicle, however no provision for incursion was included as this vehicle was not required to move in its longitudinal direction. To secure this second simulated vehicle, two hinges were attached to its wheels and the VDA. This design allowed it to rest on its printed face and be swung up to its vertical position with ease. When in its vertical position, latches attached to the back of the truss were fastened to lag bolts previously driven into the VDA.

The concept of using foam test obstacles for this study was carefully researched, as outlined in Section 2.3. Alternatives such as inflatable cars were considered, however achieving the desired level of detail and crash worthiness proved to be impossible or cost prohibitive. Unfortunately, the silk-screening process used for the simulated incursion vehicle resulted in poor color quality. This foam test obstacle was intended to simulate a teal-colored Saturn, however, the final product was dark blue in color. This shade of dark blue was, however, identical to a 1995 Dodge Neon, which had been purchased for another test program but was available for use in this test. For this reason, and the fact that the cars have very similar silhouettes, the real Dodge Neon and the polystyrene Saturn SC were used as the real and artificial vehicles in the right-side crossing lane.

3.5.3. Mechanics of Incursion Scenario Implementation

Figure 6 shows the position of all vehicles involved in the incursion scenario, except the lead vehicle. Projection of the simulated incursion vehicle (vehicle B) into the intersection was accomplished by attaching a thin cable (fishing line) from the front of the simulated incursion vehicle to the rear of a tow vehicle, a 1996 Honda Accord V6. The tow vehicle was located far enough from the intersection to prevent it from attracting subjects' attention or being in a vulnerable position in the event that the subject lost control of the test vehicle. When the subject vehicle drove over a pressure-sensitive tape switch positioned at either 165 or 198 feet (50.3 or 60.4 m) from the center of the intersection (corresponding to the 2.5 and 3.0 second times to intersection, respectively), an LED display near the tow vehicle was illuminated, alerting its driver to pull the simulated vehicle into the intersection. The Accord was accelerated at approximately 4.9 m/s^2 for 1.1 seconds and stopped. This towed vehicle B a total of 16 feet (4.9 m), or 6 feet (1.8 m) into the intersection, to yield a partial incursion (as illustrated in Figure 7). To ensure that it traveled in a straight line, four eye screws were attached to vehicle B and its truss. The eyes allowed vehicle B to run along two 3/16 inch (0.5 cm) high-tension cable guides anchored to the VDA, and enabled testing to be done in windy conditions. Due to their proximity to the ground, the lead and subject vehicles were able to pass over the cables without sustaining damage. To prevent vehicle B's inertia from carrying it beyond the 6 foot (1.8 m) incursion level, redundant stops were used. A cable allowing only 16 feet (4.9 m) of travel was attached to the rear of vehicle B and anchored into the VDA. A second stop was positioned on the front cable tether. If the cable stop was to fail, the eye screw connecting the front of vehicle B to the cable would reach the secondary stop and impede any further motion.

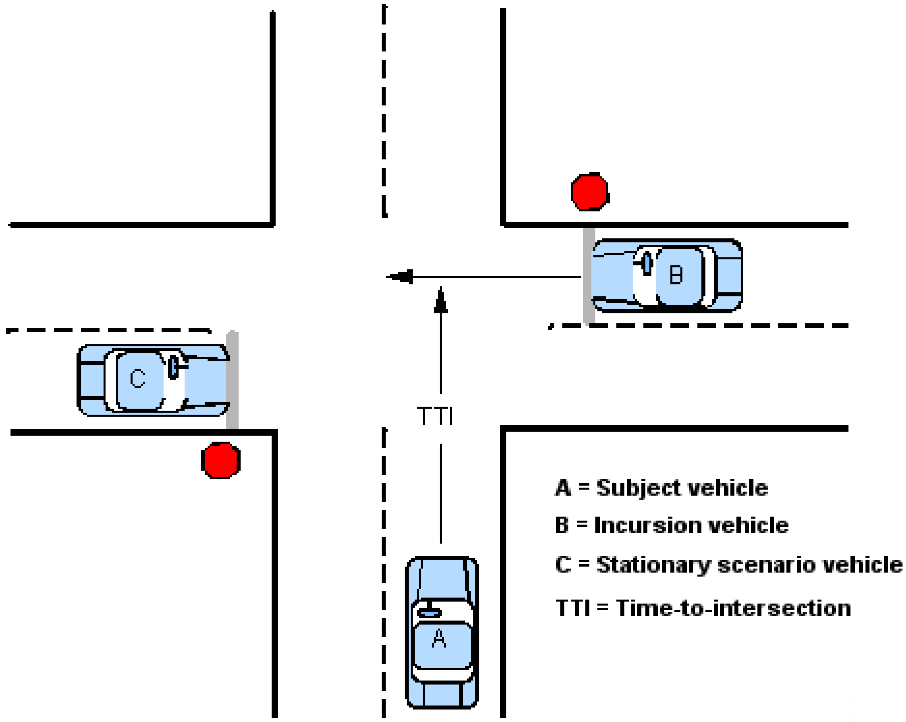

Figure 6. Illustration of intersection layout and vehicle positioning prior to the incursion.

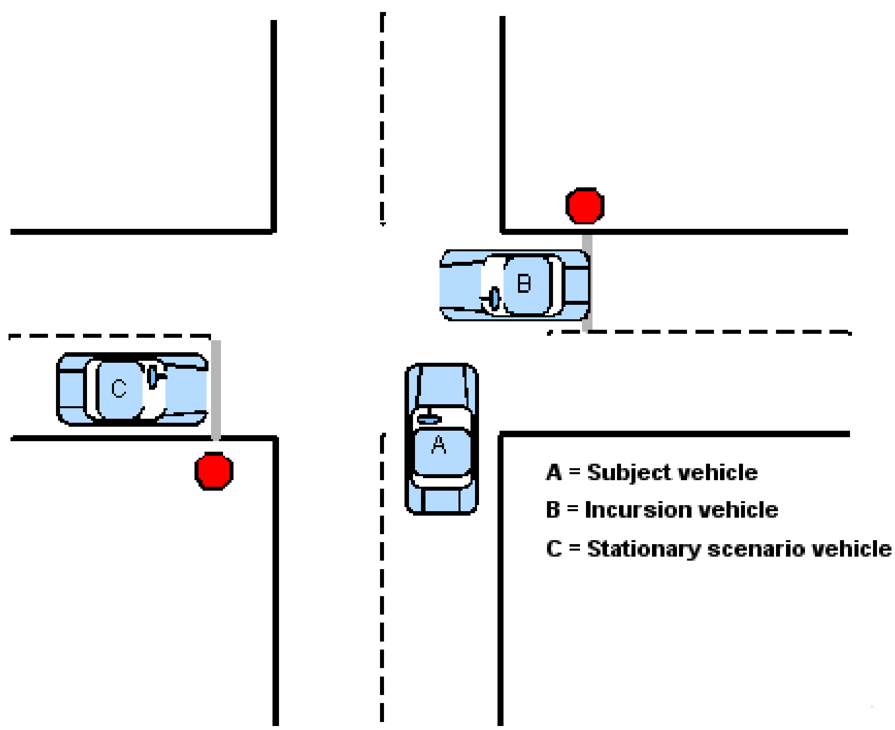

Figure 7. Illustration of incursion vehicle position after the incursion.

3.5.4. Scenario Implementation Procedure

Two vehicles were positioned at the intersection at the stop lines of the crossing lane (a blue 1995 Dodge Neon coupe on the right and a silver 1992 Saturn SC on the left) as shown in Figure 8. To examine subjects' behavior in response to an unexpected intersection incursion, the car at the right-side crossing lane was to be projected 6 feet (1.8 m) into the subject's lane of travel. For safety reasons, the actual vehicles were replaced with realistic artificial vehicles constructed of polystyrene foam prior to the presentation of the incursion scenario on the subject's fourth lap of the test course.

The lead vehicle guided the subject vehicle through the intersection a total of four times. After the lead and subject vehicles passed through the intersection a second time and were approaching the entrance to the south VDA loop, three support persons emerged from a large tent located approximately 400 feet (121.9 m) to the west of the intersection. One person entered the silver Saturn, sat in the driver's seat, closed the door, positioned his hands on the steering wheel and looked straight ahead. The other two people entered the Neon, one in driver's seat and one in the back seat. The person in the rear seat crouched down, and the driver prepared himself in the same manner as the driver of the silver Saturn. The lead and subject vehicles soon drove through the intersection for the third time, passing as they had done twice before but now with people in the drivers' seats of the Neon and Saturn. Having people in the drivers' seats mimicked the drivers that appeared to be present in the artificial vehicles. After the lead and subject vehicles passed through the intersection the third time and were approaching the south VDA loop, the set-up procedure for vehicle B and vehicle C was begun.

The driver of the silver Saturn exited the car, lifted vehicle C into place, and latched it to the VDA. The driver quickly re-entered the Saturn, departed the intersection with the vehicle and parked just north of the tent--out of sight of the lead and subject vehicles as they approached their fourth pass through the intersection. The driver then exited the Saturn, entered the Accord towing vehicle, and waited for the signal from the tape switch to indicate vehicle B launch time.

While the driver of the Saturn was busy preparing vehicle C, the driver and back seat occupant of the Neon quickly exited their car and attached vehicle B to its cable guides. The back seat occupant then ran to a 1992 Acura Legend located approximately 200 feet (61.0 m) before (south of) the intersection, and prepared to videotape the subject vehicle's maneuver in response to the surprise incursion. While the back seat occupant was running toward the Legend, the driver of the Neon returned to the driver's seat and drove it into the tent. The driver then exited the Neon, ran to a nearby van, and drove it to a location approximately 300 feet (91.4 m) north of the intersection, facing it.

When the subject vehicle passed over the tape switch on the fourth intersection approach, the driver of the Accord was signaled. This driver, in turn, accelerated and braked. Vehicle B was pulled a total of 16 feet (4.9 m) to yield a 6 ft (1.8 m) incursion, as shown in Figure 9, and was stopped by the restraining tether and cable stop. The subject vehicle's reaction was observed and recorded during this scenario.

Figure 8. Photograph of intersection with actual vehicles in position prior to incursion scenario.

Figure 9. Photograph of intersection with foam vehicles after incursion.

3.6.

3.6 RUSE

In order to obtain realistic, unbiased driver responses to the incursion scenario presented, it was imperative to ensure that subjects would not perceive that the true purpose of the study was related to driver behavior in a crash avoidance situation or brake system issues. Therefore, experimenters created a ruse to prevent subjects from anticipating that they would be involved in this crash avoidance exercise. Subjects were told that they were participating in a study of driver behavior in which data would be collected to assess how average drivers steer and maintain speed while driving in typical driving conditions. To help ensure that subjects would not anticipate the intersection incursion event, they were informed they would be driving for approximately 30 minutes when, in actuality, the length of the drive was approximately 15 minutes. A high technology device, described below, was also introduced for their use part-way into the test to disguise the purpose of the test. Subjects were told that their task was to drive normally and that they would be given a questionnaire to collect information regarding their impressions of the drive and use of the high technology device.

3.7. TEST PROCEDURE

3.7.1. Subject Pre-Brief Procedure

Upon arrival for testing, the subject was asked to read over the information summary letter (see Appendix C) containing information regarding test procedures, and prepare to sign an informed consent statement. The staff member conducting the pre-brief session also made observations about the level of alertness and mood of the subject and recorded them on the Subject Data Form (see Appendix D).

Before beginning the test, some subjects were shown a video tape containing ABS instruction that highlighted the function, behavior, and use of an antilock brake system. An outline that lists the points covered in this instructional video is included in Appendix E. This video also contained segments addressing seat belt usage and air bag function that were added by the research staff in an effort to disguise the focus of the study. Providing comparable video instruction for the conventional brake condition was desired to prevent confounding of the data, however, as indicated in Table 1, no instruction was provided to subjects in the conventional brake system condition. This was primarily due to the unavailability of a high quality instructional video for outlining the operation and techniques for use of a standard brake system and because it was assumed that people know how to use conventional brakes.

3.7.2. In-Vehicle Procedure

Upon entering the test vehicle, subjects were required to listen to audio instructions played from a compact disc (CD) by the experimenter. Scripts for these pre-recorded instructions are contained in Appendices F and G. An initial track was played to briefly describe the overall test. Later, other separate CD tracks were played throughout the test to describe braking practice procedures (if applicable) and the use of a high technology device that was used as a distractor task. Since no braking practice was conducted in the wet pavement testing, the pre-recorded instructions varied slightly from those used in the dry pavement testing. A script of these instructions is provided in Appendices F and G.

Braking Practice Procedure. Braking practice was provided to half of the subjects in each of the two brake system conditions in the dry pavement study. Although the effect of practice with

ABS on subjects' ability to avoid a crash was of primary interest, braking practice was provided to a portion of subjects in each brake condition to prevent confounding of data by giving those driving ABS-equipped test vehicles more familiarity with the vehicle before experiencing the incursion scenario. This practice gave subjects driving an ABS-equipped vehicle the opportunity to experience the brake pedal feedback present in current ABS. Braking practice was only conducted in the dry pavement study since the location of the intersection in the wet pavement study was the same surface as that used for braking practice.

Before starting on the test route, subjects in the "braking practice" condition were given the opportunity to practice a braking maneuver involving obstacle avoidance on a wet Jennite-covered asphalt (low coefficient of friction) surface. Subjects were instructed by the in-vehicle experimenter (see Appendix F) to approach a coned lane at 35 mph (56 kph), drive through the lane maintaining that speed, and then at a certain point, brake and steer the vehicle as needed to avoid a traffic cone centered in the lane ahead. Subjects were not told exactly how to avoid hitting the cone, but were merely instructed to do whatever they felt was necessary and appropriate to do to avoid hitting it. Input provided to the subjects during this practice was constrained to a limited range of possible comments regarding their performance in order to prevent confounding of results by allowing variation of the level of oral instruction provided to subjects. Subjects repeated the maneuver two times for a total of three practice trials.

Test Drive. At all times when a subject was in the test vehicle, an experimenter was present in the back seat to direct them through the test route. Subjects were instructed by the experimenter to drive on the specified course. A "lead" vehicle operated by a professional driver was scripted to drive by on the course in front of the subject vehicle at the precise moment that the subject was ready to start onto the course. As the lead vehicle passed, the subject was told, "There's another subject in the study just like you; please turn onto the course behind them and begin your drive." The purpose of this vehicle was to help encourage subjects to believe that if the lead vehicle made it through the intersection without incident that the subject vehicle would do the same. In addition, this lead vehicle encouraged subjects to maintain the specified speed limit. Subjects were instructed to drive in their normal manner and maintain a speed of 45 mph (72 kph) on dry pavement or 35 mph (56 kph) on wet pavement.

Each subject completed 3.5 laps of the course. After the first lap, subjects were instructed to begin using a high technology "Laser Rangefinder" device installed on the test vehicle. This device consisted of a laser mounted in the grill of the test vehicle that detected the distance to a forward vehicle. A display was mounted at the center of the dashboard that showed the distance information. Subjects were told to use the information provided by the display in order to maintain a distance of 200 feet (61.0 m) from the forward vehicle that was traveling at the specified speed limit for that study. Use of the system provided a distraction for subjects, helped to prevent them from realizing the true aim of the test, and also helped them maintain the desired travel speed.

As the lead and subject vehicles passed through the intersection the first two times, the actual scenario vehicles were positioned at the intersection. Between the third and fourth laps, the artificial vehicles were set in place and the real scenario vehicles were then removed to a remote location out of view of the subject. When the subject passed over the tape switch on the fourth lap, the simulated vehicle was towed into the lane and stopped with the front of the vehicle 6 feet (1.8 m) into the subject's lane of travel as illustrated in Figure 9. Following this event the experiment ended. The in-vehicle experimenter completed an in-vehicle data log sheet (see Appendix H) to record the test conditions and characteristics of the subject's response and scenario outcome. Meanwhile, subjects were instructed to drive the vehicle from the test area back to the lab where debriefing would take place. A script of the post-test debrief is contained in Appendix I.

3.7.3. Post-Drive Questionnaire

A member of the research staff met the subject at the test vehicle as they returned to the test starting point in the lab parking lot. The staff member escorted the subjects back to the building and asked them about their thoughts on the drive in order to capture their immediate impressions of the drive that were still fresh in their memory since the incursion scenario event had taken place less than 10 minutes prior. Notes were recorded regarding the subjects' statements. The subjects were then asked to complete a questionnaire (Appendix J) containing questions regarding their personal vehicle, their personal driving experience, their impressions of the test drive, and the realism of the incursion scenario.

3.8. DATA ANALYSIS

Data analysis focused on classifying and decomposing subjects' reactions to the obstacle avoidance scenarios. Steering and braking inputs were examined as well as the timing and interaction between the two. Subjects' reactions were classified as braking only, braking and steering, or steering only. Steering reactions were recorded both in terms of magnitude of initial steering reaction and range of total steering maneuver to avoid the crash. The brake reaction sequence began when the artificial vehicle (foam car) began its incursion sequence. Brake reaction time was made up of three parts: 1) throttle release, 2) accelerator to brake transition time, and 3) brake depression. In addition, the severity of the braking input was noted in terms of brake pedal force and longitudinal acceleration, as well as whether or not the wheels locked or ABS activated. Lane position variance and whether the vehicle left the marked roadway were also recorded during each obstacle avoidance scenario.

Inferential analyses of driving performance measures were performed. For each applicable measure, an analysis of variance was performed with Type III sum of squares using SAS. Questionnaire data were summarized using descriptive statistics.

3.8.1. Determination of ABS Activations and Instances of Wheel Lockup

Cases of wheel lockup and ABS activation were determined through examination of sensor data collected during testing. Time series data channels were reviewed for each crash avoidance maneuver including brake line pressures, applied brake pedal force, individual wheel speeds, and vehicle travel speed. The occurrence of wheel lockup was indicated by one or more wheel speed channels approaching zero while the vehicle travel speed was greater than zero. An instance of ABS activation was considered to have occurred if, during a crash avoidance maneuver involving braking, any of the brake line pressure sensors measured a dump in line pressure followed by a build in line pressure without a corresponding increase in force applied to the brake pedal. Individual wheel speed channel data were also observed during the time of the crash avoidance maneuver to determine whether evidence of ABS activation was present. In a stopping maneuver in which ABS was activated, momentary wheel slip followed by a recovery back to nearly ground speed could be observed in one or more wheel speed data channels. Plots containing sensor data indicating instances of wheel lockup and ABS activation are provided in Figures 10 and 11, respectively.

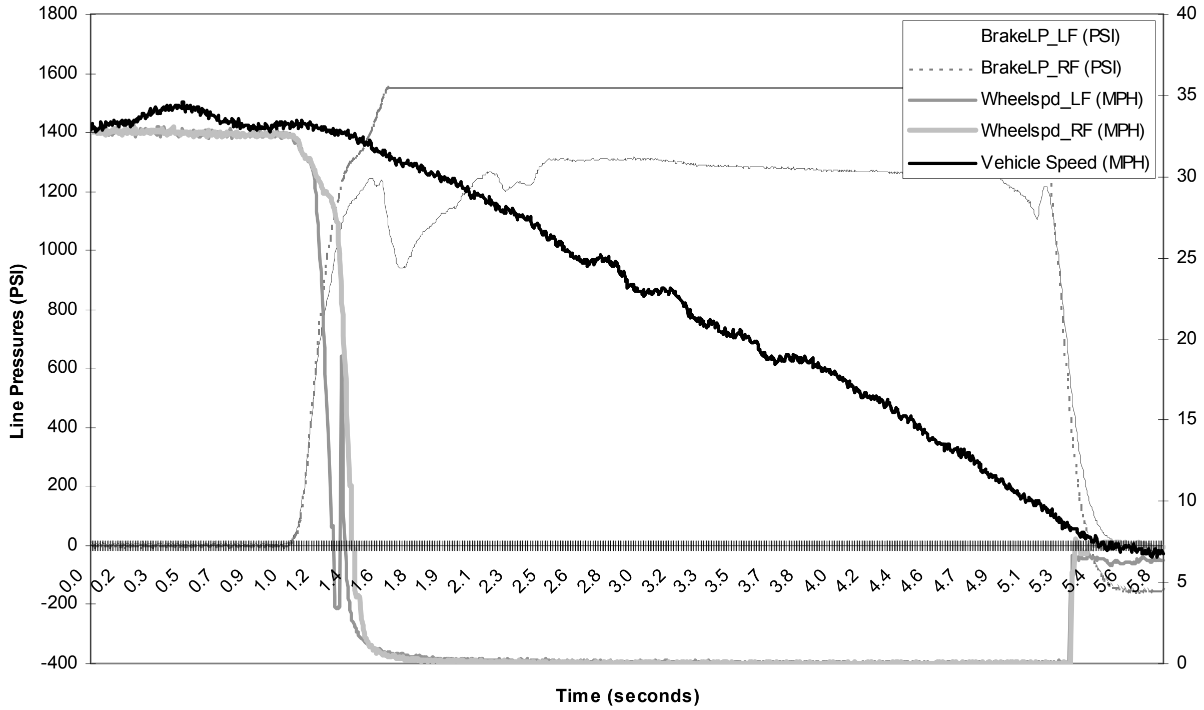

Figure 10. Sensor data plot showing evidence of wheel lockup.

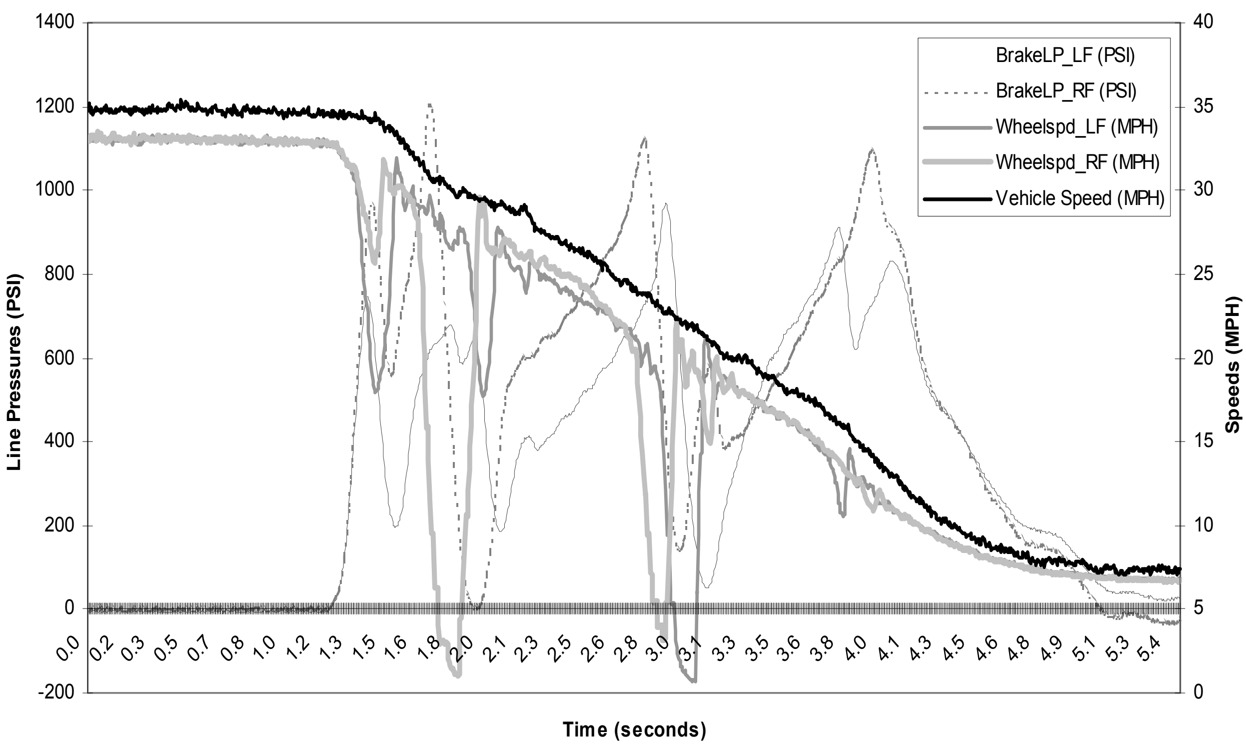

Figure 11. Sensor data plot showing evidence of ABS activation.

4.0 RESULTS

This section contains results pertaining not only to the comparison of subjects' behavior and crash avoidance performance with ABS versus with conventional brakes in an intersection incursion scenario, but also provides additional data which quantitatively define the range of responses and response characteristics exhibited by subjects in the intersection incursion scenario used in this research. For example, these data provide information about how much drivers tend to turn the steering wheel under the crash-imminent conditions examined and how fast they make these steering inputs. Information is also provided which helps define driver braking behavior, such as how hard people tend to press on the brake pedal. Reaction time data is also useful in the consideration of how quickly people tend to respond in crash imminent situations of this type. These data describing drivers' typical responses in a crash imminent situation are useful to researchers in performing a variety of tasks relating to crash investigation, vehicle stability and control, human (driver) performance, and other topics unrelated to ABS research. Although the inclusion of these data results in a lengthy discourse on the quantitative measures obtained, the authors feel that the benefits of providing this information to the research community are worthwhile.

Results are presented here according to the individual independent variables as well as according to aspects of the observed crash avoidance strategies used. For each independent variable, data for all pertinent measures are provided. A separate analysis of variance (ANOVA) was conducted for each applicable measure and results are presented in this section. Significance tests for categorical measures used the Chi-Square test. Statistical metrics indicating level of significance are listed for all statistically significant results. If no statistical significance results are listed explicitly in the text, then the values were not significantly different.

4.1. USEFUL DEFINITIONS

A number of terms are used to describe subjects' responses in an attempt to avoid a crash in this intersection incursion scenario. This section provides brief definitions of those terms.

The following terms describe measures used to describe the behavior of the subject vehicle immediately prior to the intersection incursion presentation as well as the beginning of the subjects' reactions to the incursion.

Scenario Entrance Speed - The speed at which the subject vehicle was traveling as it approached the simulated intersection immediately prior to the presentation of the intersection incursion scenario.

Reaction Time - The time from when the incursion vehicle began to move into the intersection until the subject initiated some specific action, e.g., throttle release, steering input, etc. All reaction times were measured from the moment of the initiation of the scenario vehicle's incursion motion. The data for five subjects who began to react prior to the initiation of the incursion vehicle's motion were not included in reaction time calculations.

Throttle Release - The point at which the subjects removed their foot from the throttle as determined by the degree of depression of the gas pedal.

Initial Reaction - The first action taken by a subject in response to the intersection incursion. Possible reactions include throttle release, steering input, and applying the brakes (if the person braked with the left foot prior to releasing the throttle).

Subjects' steering maneuvers in an attempt to avoid colliding with the incursion vehicle were broken down into individual inputs for classification and analysis. Subjects' steering inputs were classified as follows: initial input, avoidance input, and lane position recovery input. Definitions for these and other related terms are given below.

Steering Input - Any single-directional movement of the steering wheel greater than 6 degrees.

Initial Steering Input - The subject's first steering input in response to the incursion vehicle's motion.

Time to Initial Steering Input (Initial Steering Response Time) - The time from when the incursion vehicle began to move into the intersection until the time the subjects initiated their first steering input in an attempt to avoid a crash.

Initial Steering Input Magnitude - The peak value of the first steering input following the start of the incursion vehicle's motion. Since prior to the incidence of the initial steering input the subjects were going straight, the initial steering input magnitude was also the initial steering input range.

Avoidance Steering Input - The steering input which the subject intended to cause the subject vehicle to travel around the incursion vehicle in an attempt to avoid colliding with it; i.e., the steering input which was in progress as the subject vehicle passed through the plane of motion of the incursion vehicle.

Avoidance Steering Input Magnitude - The peak value of the steering input which the subjects made to maneuver their vehicle around the incursion vehicle.

Avoidance Steering Input Range - The total number of degrees in a single direction that the subject moved the steering wheel through in an effort to steer around the incursion vehicle.

Time to Maximum Steering Input - The time from when the incursion vehicle began to move into the intersection until subjects initiated their largest steering input during the crash avoidance maneuver.

Maximum Steering Input Magnitude - The peak value of the largest steering input which the subjects made to maneuver their vehicle around the incursion vehicle.

Maximum Steering Input Rate - The peak value of steering input rate values obtained for each subject during the crash avoidance maneuver.

First Lane Recovery Steering Input Range - The total number of degrees in a single direction that the subjects moved the steering wheel through in an effort to recover their lane position on the road and return the test vehicle to the original lane of travel.

Total Number of Steering Inputs Made During the Avoidance Maneuver - Total number of steering inputs observed in response to the incursion scenario with the first input being the initial input and including any intermediate inputs made between the initial and avoidance inputs as well as up to two lane recovery inputs.

Figure 12 illustrates the terms used to describe the different components of the steering maneuver where:

A = Initial steering input
B = Avoidance steering input range
C = Avoidance steering input magnitude
D = First lane recovery input range
E = Second lane recovery input range.

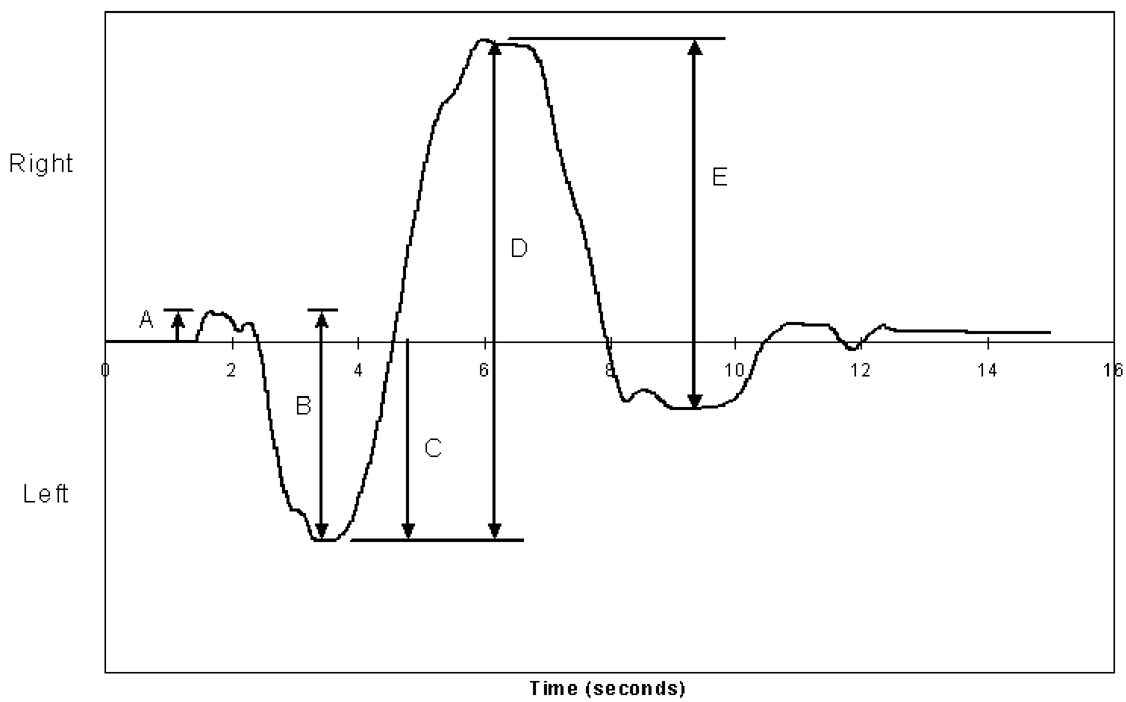

Figure 12. Illustration of steering input definitions for a subject whose initial steering input was in the opposite direction of the avoidance steering input.

Figure 13 illustrates these terms for the case in which subjects' initial steering input was also their avoidance steering input.

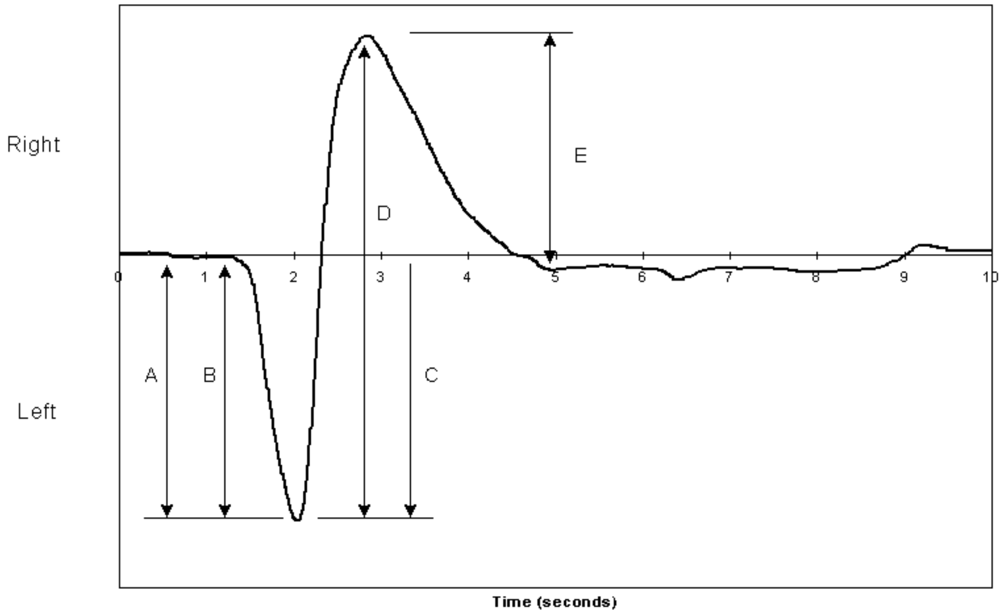

Figure 13. Illustration of steering input definitions for a subject whose initial steering input was the same as the avoidance steering input.

Additional terminology was also introduced to describe subjects' braking inputs. Definitions of these additional terms related to braking behavior include:

Time to Initial Brake Input (Brake Reaction Time) - The time from when the incursion vehicle began to move into the intersection until the subject first applied force to the brake pedal (as determined by brake light illumination).

Throttle to Brake Application Transition Time - The length of time that lapsed from when the throttle was released to when the subject first applied force to the brake pedal (as determined by brake light illumination).

Throttle to Maximum-Brake Application Transition Time - The length of time that lapsed from when the throttle was released to when the maximum amount of force was applied to the brake pedal.

Time to Maximum Brake Input - The time from when the incursion vehicle began to move into the intersection until the subject applied a maximum amount of force to the brake pedal.

Maximum Brake Pedal Force - The maximum observed amount of brake pedal pressure applied by the subject during the crash avoidance maneuver.

Brake Pedal Application Duration - The length of time that force was applied to the brake pedal during a crash avoidance maneuver.

It should be noted that the average delay from application of force to the brake pedal until the brake light illuminated was approximately 0.06 seconds. This delay time is present in measures of "time to initial brake input" and "throttle to brake application transition time".

Lastly, road departures were defined as follows:

> *Full Road Departure* - A road departure in which all four of the test vehicle's wheels left the boundaries of the two defined travel lanes.
>
> *Partial Road Departure* - A road departure in which only one or two of the test vehicle's wheels left the boundaries of the two defined travel lanes.

4.2. OVERALL

A summary of overall results for the various dependent measures are provided in the following sections. Please note in regard to this summary of results that two TTI values were used in the dry pavement study (2.5, 3.0 seconds) as opposed to only one in the wet pavement study (2.5 seconds). In addition, braking practice was not provided in the wet pavement study.

4.2.1. Scenario Entrance Speeds - Overall

The speed limits used in this research were 45 miles per hour (mph) on dry pavement and 35 mph on wet pavement. Since drivers do not always consistently travel at the speed limit, it is important to show a breakdown of the actual speeds of travel immediately before a reaction occurred in response to the incursion. This instantaneous recording of speed prior to the event will be denoted as scenario entrance speed throughout this report. In the dry pavement study, the mean scenario entrance speed across subjects was 44 mph (standard deviation (SD) 2, max 50, min 27). In the wet pavement study, the mean scenario entrance speed was 34 mph (SD 2, max 37, min 28). Subjects maintained the required speed limit well in these studies. Accurate speed maintenance was desired since TTI values were based on an assumed scenario entrance speed (the speed limit).

4.2.2. Initial Reactions and Reaction Times - Overall

Tow Vehicle Driver Reaction Time. The reaction time of the tow vehicle driver was measured to quantify its potential effects on other timing related measures. A video camera was used to record both the tow vehicle's left-front wheel and the LED which was connected to the pressure-sensitive tape switch positioned before the intersection and signaled the tow vehicle driver to perform the incursion. Reaction time was determined by counting the number of video frames from when the LED illuminated until the wheel of the tow vehicle began to roll. Examination of a subset of trials showed that the reaction time of the tow vehicle ranged from 3 to 6 frames and was consistently 200 milliseconds (ms) or less. Based on the subsample, the tow vehicle driver reaction time had a mean value of 131 ms.

Reaction Time. Reaction times could be determined for all subjects based on their initial throttle, brake, and steering responses to the incursion of the scenario vehicle. All reaction times were measured from the moment of the initiation of the scenario vehicle's incursion motion. The start of the incursion was determined using the sensor data channel corresponding to the pressure-sensitive switch that triggered the start of the incursion. Channels corresponding to switch triggering, steering, and braking could be superimposed to determine the timing of subjects' responses.

Mean initial reaction times are presented in Table 4. As stated previously, the data for five subjects who began to react prior to the initiation of the incursion vehicle's motion were not included in reaction time calculations, but were included in transition time calculations. Some subjects' responses were found to coincide with the initiation of the incursion (as indicated by the minimum initial reaction time value of 0).

Throttle Release as Initial Reaction. Ninety-two percent of 192 subjects in the dry pavement study and 91 percent of 53 subjects in the wet pavement study released the throttle as their initial response. The mean throttle release time values in response to the incursion event are listed in Table 4. Four subjects who released the throttle prior to the incursion vehicle's motion on dry pavement and one who did so on wet pavement were not included in these means.

Steering Input as Initial Reaction. Those who did not release the throttle as an initial reaction, steered instead, as shown in Table 5. The "initial steering input" was the first single-directional input of magnitude greater than 6 degrees observed after the incursion vehicle began to move. Results for mean time to initial steering input are discussed in Section 4.2.5.

Table 4. Crash avoidance strategy prevalence and related crash results.

INITIAL REACTION	Dry					Wet				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Initial Reaction Time (any input)	189	1.17	0.31	0	2.14	51	1.09	0.28	0.20	1.80
Time (s) to Throttle Release	188	1.19	0.29	0.55	2.14	51	1.12	0.28	0.20	1.80

Table 5. Percent of subjects that released throttle and percent that steered as initial reaction.

INITIAL REACTION	Dry	Wet
Throttle Release (%)	92	91
Steering Input (%)	8	9

4.2.3. Transition Times

Transition times were calculated for the initial responses (e.g., throttle release to initial brake application time) as well as between the initial responses and their respective maximum reactions (e.g., time from initial brake application to maximum brake application).

Brake Input Transition Times. The mean throttle-release-to-brake transition times are listed in Table 6. Five subjects in the dry pavement study exhibited atypical behavior in transitioning from throttle application to braking, causing the minimum throttle-release-to-brake transition time to be negative. These included two subjects who applied force to the brake pedal with the left foot before releasing the throttle with the right foot and three subjects who were able to release the throttle and apply force to the brake pedal with their right foot before the throttle had returned to the neutral position. The mean initial brake input to maximum brake input transition time values are also shown in Table 6.

Table 6. Brake Input Transition Times.

BRAKE INPUT MEASURE	Dry					Wet				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Throttle Release to Brake Input Transition Time (s)	187	0.31	0.18	-0.14	0.93	51	0.30	0.29	0.01	1.34
Initial Brake to Maximum Brake Application Transition Time (s)	191	0.80	0.52	0.04	2.69	52	0.86	0.60	0.09	3.13

Steering Input Transition Times. The values for mean time from throttle release to initial steering input are listed in Table 7. These calculations excluded those who released the throttle prior to the incursion, those who steered prior to releasing the throttle, and those subjects who did not steer as part of their avoidance maneuver. Values for the mean time from initial steering input to initiation of the maximum steering input for subjects that steered during their crash avoidance maneuver are also listed in Table 7.

Table 7. Steering Input Transition Times.

STEERING INPUT MEASURE	Dry					Wet				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Throttle Release to Initial Steering Input Transition Time (s)	160	0.50	0.51	0	2.20	45	0.40	0.33	0.01	1.21
Initial Steering Input to Maximum Steering Input Transition Time (s)	181	1.08	0.78	0.04	4.34	52	1.25	0.93	0.08	4.47

4.2.4. Crash Avoidance Strategy - Overall

A summary of subjects' crash avoidance response strategies are presented in Table 8. Subjects who both braked and steered varied by whether they braked or steered first.

Subjects who steered in an attempt to avoid a crash also varied in terms of the direction in which they steered initially and the direction in which they steered to avoid a crash. A subject's initial steering input was not necessarily the maneuver used in an attempt to avoid the incursion vehicle, i.e., the "avoidance steering input". Differentiating between initial and avoidance steering inputs provided some information regarding how many subjects changed the direction of their steering input while trying to avoid a crash with the incursion vehicle. Overall, 29 percent of 192 subjects on dry pavement and 26 percent of 53 subjects on wet pavement changed the direction of their steering between the initial and avoidance inputs. Subjects who did not change the direction of their steering input were 65 percent of 192 subjects on dry pavement and 72 percent of 53 subjects on wet pavement. Table 9 provides a breakdown of these results by steering direction and related crash results. Tables 10 and 11 contain data describing the number of subjects who changed steering direction on dry and wet pavement and related crash results.

Table 8. Crash avoidance strategy prevalence and related crash results.

DRIVER INPUT	Dry		Wet	
	% Action	% Crashed	% Action	% Crashed
Braked and Steered	94	39	98	71
- Braked then Steered	45	39	46	79
- Steered then Braked	49	38	52	64
Braked Only	5	60	2	100
Steered Only	0	NA	0	NA
No Response	1	100	0	NA

Table 9. Percentage of responses by steering input direction and related crashes by pavement condition.

STEERING INPUT MEASURE	Direction of Steering Input	Dry		Wet	
		% Steered	% Crashed	% Steered	% Crashed
Initial Steering Input	Left	63	40	68	69
	Right	31	34	30	75
	None	6	67	2	100
Avoidance Steering Input	Left	76	36	75	70
	Right	18	47	23	75
	None	6	67	2	100

Table 10. Percentage of avoidance steering inputs in a particular direction based on initial steering direction and related crashes for the **dry** pavement condition.

DIRECTION OF INITIAL STEERING INPUT	% Steered	Direction of Avoidance Steering Input	% Steered	% Crashed
Left	63	Left	88	38
		Right	12	60
Right	31	Left	68	33
		Right	32	37

Table 11. Percentage of avoidance steering inputs in a particular direction based on initial steering direction and related percent of crashes for the **wet** pavement condition.

DIRECTION OF INITIAL STEERING INPUT	% Steered	Direction of Avoidance Steering Input	% Steered	% Crashed
Left	68	Left	86	71
		Right	14	60
Right	30	Left	56	67
		Right	44	86

In some cases, a subject's first steering input was that which he or she intended to cause the test vehicle to maneuver around the incursion vehicle. In this case, the "initial steering input" was also the "avoidance steering input". Overall, 36 percent of subjects (69 subjects) in the dry pavement study and 19 percent of subjects (10 subjects) in the wet pavement study had an initial steering input that was also their avoidance steering input.

4.2.5. Steering Behavior - Overall

Subjects' steering behavior during the crash avoidance maneuver was decomposed into a series of individual inputs: an initial input, an avoidance input, and a lane position recovery input. The initial steering inputs observed were easily identifiable, even in situations in which a subject's initial and avoidance inputs were in the same direction. These initial steering inputs tended to be smaller in magnitude than the avoidance inputs. Some subjects made steering inputs between the initial and avoidance inputs. Some subjects also made multiple lane recovery steering inputs, although the first lane recovery input was the only one analyzed since it was considered the most likely to be realistic. Due to the potentially large number of steering inputs, the total number of steering inputs attempted by subjects in response to the incursion scenario was also examined. Various aspects of steering input magnitude, rate, and timing were examined as outlined below. Results for steering behavior measures are summarized in Table 12.

Time to Initial Steering Input. Values for the mean length of time subjects took to make their first steering input in response to the intersection incursion are shown in Table 12.

Initial Steering Input Magnitude. Results for the mean magnitude of subjects' initial steering input are also presented in Table 12.

Table 12. Selected steering input results.

STEERING INPUT MEASURE	Dry					Wet				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Time (s) to Initial Steering Input	181	1.65	0.58	0	4.26	52	1.44	0.42	0.69	2.71
Initial Steering Input Magnitude (degrees)	179	29	34	6	276	52	31	28	7	109
Avoidance Steering Input Magnitude (degrees)	180	53	43	2	271	52	74	64	7	289
Avoidance Steering Input Range (degrees)	176	56	46	7	276	52	75	80	7	400
Time (s) to Maximum Steering Input	182	2.72	0.85	1.17	6.72	52	2.69	0.96	1.04	5.85
Maximum Steering Input Magnitude (degrees)	181	57	45	6	271	52	76	62	7	289
Maximum Steering Input Rate (degrees)	182	262	200	30	1159	53	294	237	33	1335
First Lane Recovery Steering Input Range (degrees)	166	100	70	5	418	52	102	74	7	324
Total Number of Steering Inputs Made During Crash Avoidance Maneuver	179	3.9	1.5	1	8	52	4.7	1.6	2	11

Avoidance Steering Input Magnitude. The "magnitude of the avoidance steering input" was defined as the peak value of that input. Results for mean avoidance steering input magnitudes are listed in Table 12. The highest observed steering input from an individual subject during the avoidance maneuver in the dry pavement study was 271 degrees. The highest such value for the wet pavement study was 289 degrees.

The magnitude of subjects' avoidance steering inputs were examined based on whether their crash avoidance strategy was to brake and then steer, to steer and then brake, or to steer only. These results and related crash percentages are presented in Table 13.

Table 13. Average of avoidance steering input magnitudes and related crash results by crash avoidance strategy.

DRIVER INPUT	Dry		Wet	
	Mean Magnitude of Avoidance Steering Input	**% Crashed**	**Mean Magnitude of Avoidance Steering Input**	**% Crashed**
Braked and Steered	53	39	74	71
- Braked Then Steered	52	39	72	79
- Steered Then Braked	54	38	76	64
Steered Only	NA	NA	NA	NA

Avoidance Steering Input Range. Results for mean avoidance steering input range are listed in Table 12. The highest observed steering input range from an individual subject during the avoidance maneuver in the dry pavement study was 276 degrees. The highest such value for the wet pavement study was 400 degrees. Table 14 provides a breakdown of mean avoidance steering input range values based on crash avoidance strategy.

Table 14. Average avoidance steering input ranges and crash results by crash avoidance strategy.

DRIVER INPUT	Dry		Wet	
	Mean Range of Avoidance Steering Input	**% Crashed**	**Mean Range of Avoidance Steering Input**	**% Crashed**
Braked and Steered	56	39	75	71
- Braked Then Steered	55	39	81	79
- Steered Then Braked	56	38	70	64
Steered only	NA	NA	NA	NA

Time to Maximum Steering Input. Results for the mean length of time that passed from the time that the incursion vehicle began to move until the subjects reached their largest steering input are listed in Table 12.

Maximum Steering Input Magnitude. The results for mean maximum steering input magnitude are listed in Table 12.

Maximum Steering Input Rate. The results for mean maximum steering input rate obtained during the crash avoidance maneuver are listed in Table 12. The highest observed steering input rates were 1159 degrees per second on dry pavement and 1335 degrees per second on wet pavement. Ninety-five percent of steering rates observed were less than 600 degrees per second on dry pavement and less than 643 degrees per second on wet pavement. Figure 14 shows a frequency distribution of maximum steering input rate by pavement condition.

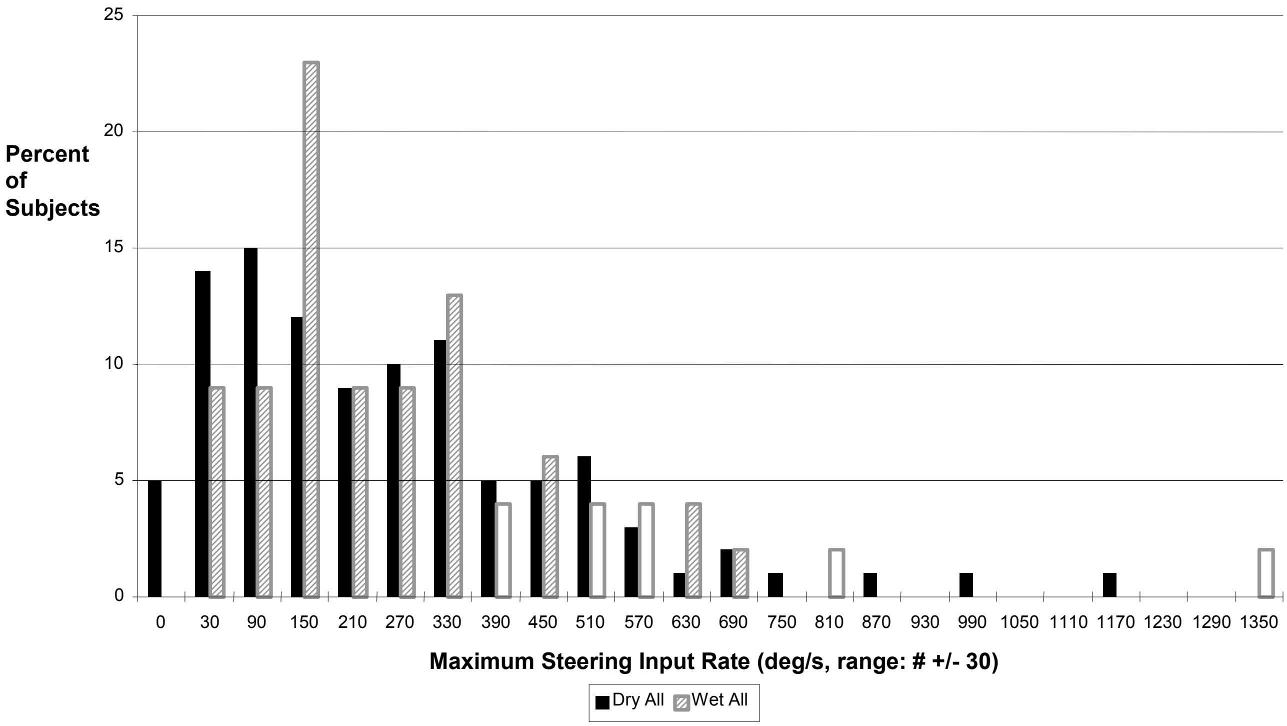

Figure 14. Maximum steering input rate frequency distribution by pavement condition.

First Lane Recovery Steering Input Range. The results for mean values obtained for the range of subjects' first lane recovery steering input are listed in Table 12.

Total Number of Steering Inputs Made During the Avoidance Maneuver. The mean total number of steering inputs observed during the crash avoidance maneuver can be found for each pavement condition in Table 12.

4.2.6. Braking Behavior - Overall

Time to Initial Brake Input. Brake reaction time was defined as the time from when the incursion vehicle began to move to when the subject's foot first made contact with the brake pedal. Results for overall mean brake reaction time are listed in Table 15.

Throttle to Brake Application Transition Time. The amount of time it took a subject to move his or her foot from the throttle to the brake pedal was also examined. Values for this measure are shown in Table 15.

Time to Maximum Brake Input. Results for mean time to maximum brake pedal force application are listed in Table 15.

Throttle Release to Maximum Brake Application Transition Time. The results for mean time from throttle release to maximum brake pedal force application are also contained in Table 15.

Maximum Brake Pedal Force. The highest observed brake pedal force input generated by a subject on dry pavement was 188 pounds. In the wet pavement study, the highest observed brake pedal force input generated by a subject was 240 pounds. Results for overall mean maximum brake pedal forces are presented in Table 15. Figure 15 shows a frequency distribution of brake force by pavement condition.

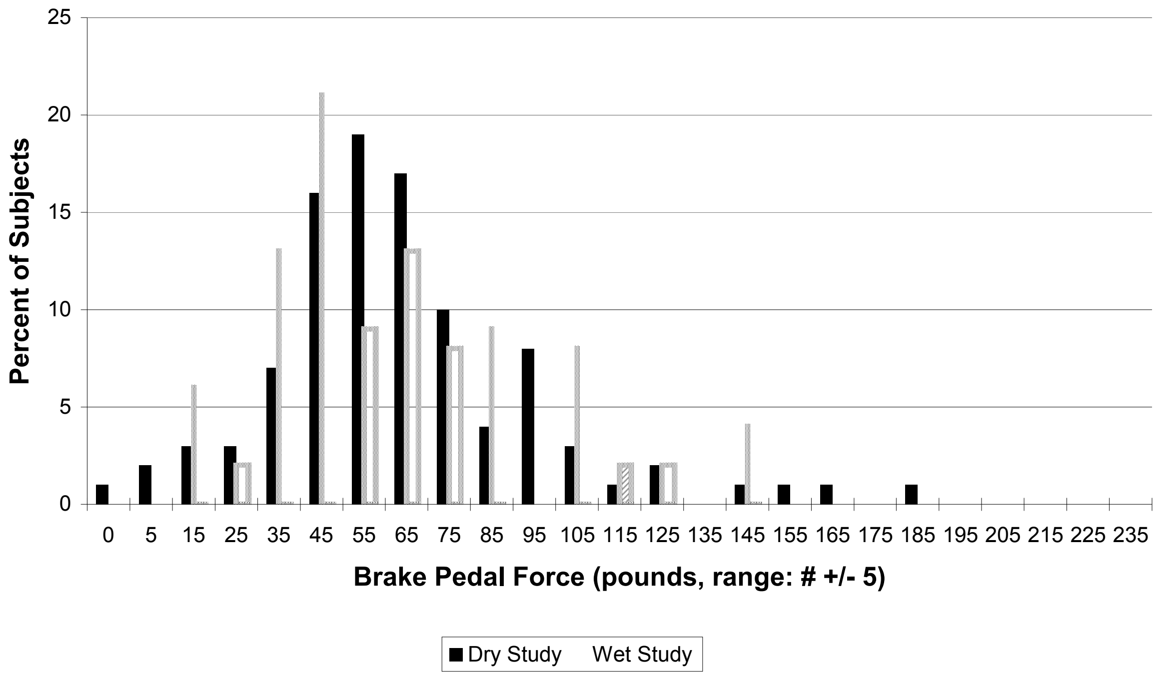

Figure 15. Maximum brake pedal force frequency distribution by pavement condition.

Table 15. Selected braking input results.

BRAKE INPUT MEASURE	Dry					Wet				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Time (s) to Initial Brake Input	191	1.50	0.30	0.61	2.34	52	1.42	0.34	0.88	2.41
Throttle to Brake Application Transition Time (s)	187	0.31	0.18	-0.14	0.93	51	0.30	0.29	0.01	1.34
Time (s) to Maximum Brake Input	191	2.30	0.47	1.12	4.14	53	2.29	0.64	1.34	5.22
Throttle Release to Maximum Brake Application Transition Time (s)	190	1.15	0.62	0.24	4.04	51	1.17	0.68	0.29	4.18
Maximum Brake Pedal Force (lbs)	191	64	31	3	188	53	68	40	12	240
Brake Pedal Application Duration	191	2.13	1.26	0.01	8.90	53	2.45	2.01	0.11	7.70

Brake Pedal Application Duration. The mean brake pedal application duration times observed are also presented in Table 15. Although this is potentially a very interesting dependent variable to examine, some difficulties were encountered in analyzing the data for this measure. A discussion of these difficulties is included in Section 6 of this report. Figure 16 shows a frequency distribution of brake pedal application duration by pavement condition.

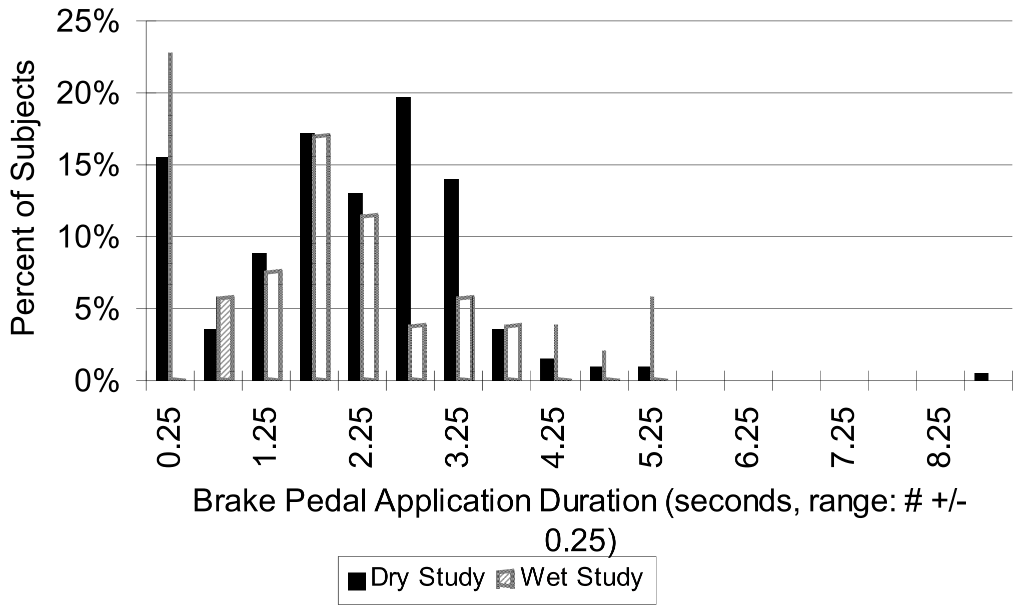

Figure 16. Brake pedal application duration frequency distribution by pavement condition.

Wheel Lockup and ABS Activations. On dry pavement, 31 percent of the 192 subjects either activated ABS or locked the vehicle's wheels with conventional brakes during the avoidance maneuver. In the wet pavement study, 96 percent of the 53 subjects either activated ABS or locked the vehicle's wheels with conventional brakes during the avoidance maneuver.

Missed Brake Pedal Applications. On dry pavement, 27 percent of 180 subjects missed the brake pedal once during their crash avoidance maneuver, 4 percent of 180 subjects missed it twice, and 7 percent exhibited a non-standard brake application technique (e.g., left foot brake, two-footed braking). On wet pavement, 8 percent of 49 subjects missed the brake pedal once, no subjects missed it twice, and 2 percent of subjects used non-standard brake application techniques. The total number of subjects per pavement condition is slightly smaller in these calculations due to the unavailability of video recorded data of foot pedal applications for a small number of subjects.

4.2.7. Longitudinal Deceleration - Overall

An analysis was conducted to determine the average maximum deceleration achieved by subjects. In the dry pavement study, the mean maximum deceleration was 0.72 g (SD 0.24, max 1.15, min 0.01). In the wet pavement study, the mean maximum deceleration was 0.45 g (SD 0.10, max 0.67, min 0.004).

4.2.8. Lateral Acceleration - Overall

Another way to assess the severity of a crash avoidance maneuver is to look at the maximum lateral acceleration of the vehicle. In the dry pavement study, the mean maximum lateral acceleration was 0.26 g (SD 0.18, max 0.73, min 0.03). In the wet pavement study, the mean maximum lateral acceleration was 0.23 g (SD 0.13, max 0.51, min 0.01).

4.2.9. Road Departures - Overall

Full Road Departures. In the dry pavement study, two subjects (out of 192) fully departed the roadway (all four wheels) during the collision avoidance maneuver. One subject steered left around the front of the incursion vehicle and ran off the road to the left. The other subject departed the road to the right after hitting the rear of the incursion vehicle. No four-wheel road departures were seen in the wet pavement study.

Partial Road Departures. In addition, two partial (one or two wheel) road departures were also observed in the dry pavement study. In the wet pavement study, only one subject experienced a partial road departure. More detailed results and discussion regarding observed road departures are provided in Section 5 of this report.

4.2.10. Crashes - Overall

During the intersection incursion event, 40 percent of 192 subjects collided with the incursion vehicle on dry pavement and 72 percent of the 53 subjects crashed on wet pavement.

4.3. BRAKE SYSTEM: ABS VS. CONVENTIONAL

Results presented for the "conventional brake system condition" include those for both test vehicles, the Lumina and the Taurus, under that brake system condition. Likewise, data presented for the "ABS condition" include data for both test vehicles while configured with the ABS operational.

In the dry pavement study, there were 128 subjects in the ABS condition and 64 subjects in the conventional brake system condition. In the wet pavement study, there were 36 subjects in the ABS condition and 17 subjects in the conventional brake system condition.

4.3.1. Scenario Entrance Speed by Brake System

Scenario entrance speeds observed are summarized in Table 16. Scenario entrance showed a significant effect of brake system on wet pavement, as indicated in the table.

Table 16. Scenario Entrance Speed by Brake System.

MEASURE	BRAKE SYSTEM	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Scenario Entrance Speed (mph)	Conv.	64	44	2	39	46	0.7369	17	33	2	28	36	0.0027
	ABS	128	44	2	27	50		36	35	1	31	37	

4.3.2. Reaction Times by Brake System

Reaction Time by Brake System. Results for mean reaction time as a function of brake system for both dry and wet pavement conditions are listed in Table 17.

Time to Throttle Release by Brake System. Results for mean time to throttle release as a function of brake system are presented in Table 17.

Table 17. Reaction Time Measures by Brake System.

MEASURE	BRAKE SYSTEM	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Reaction Time (s)	Conv.	63	1.19	0.30	0.66	2.14	0.9798	16	1.19	0.24	0.85	1.68	0.9550
	ABS	126	1.15	0.31	0	1.94		35	1.05	0.28	0.20	1.80	
Time (s) to Throttle Release	Conv.	62	1.20	0.30	0.66	2.14	0.9997	16	1.20	0.24	0.85	1.68	0.9151
	ABS	126	1.18	0.28	0.55	1.94		35	1.08	0.29	0.20	1.80	

4.3.3. Crash Avoidance Strategy by Brake System

Results for crash avoidance strategy by brake system and pavement condition are summarized in Tables 18 and 19.

Table 18. Crash avoidance strategy prevalence and related crash percentages for dry pavement.

DRIVER INPUT	% Action		% Crashed	
	Conventional (64 subjects)	ABS (128 subjects)	Conventional	ABS
Braked and Steered	94	95	47	35
- Braked Then Steered	44	46	61	29
- Steered Then braked	50	48	34	40
Braked Only	6	5	25	83
Steered Only	0	0	NA	NA
No Response	0	1	NA	100

Table 19. Crash avoidance strategy prevalence and related crash percentages for wet pavement.

DRIVER INPUT	% Action		% Crashed	
	Conventional (17 subjects)	ABS (36 subjects)	Conventional	ABS
Braked and Steered	94	100	100	58
- Braked Then Steered	53	42	100	67
- Steered Then Braked	41	58	100	52
Braked Only	6	0	100	NA
Steered Only	0	0	NA	NA
No Response	0	0	NA	NA

Figures 17 through 22 contain graphical representations of several examples of successful crash avoidance maneuvers observed in response to the incursion scenario. Driver inputs and vehicle response metrics are illustrated. Figures 17, 19, 21, and 22 illustrate the channels of vehicle speed, both front wheel speeds, applied brake pedal force, steering angle, and input rate. These channels are presented to give a general idea of the strategy and timing associated with these subjects' crash avoidance maneuvers. Figures 18 and 20 use the sensor data output for all four wheel speeds, all four brake line pressures, and applied brake pedal force to illustrate evidence of wheel lockup or ABS activation.

Figure 17 is an example of a successful avoidance maneuver in which a subject who was in the conventional brake condition steered left and then braked to maneuver around the incursion vehicle and avoid a crash (time of incursion 4.64 seconds). Figure 18 illustrates, for the same case shown in Figure 17, evidence of wheel lockup of the right front wheel.

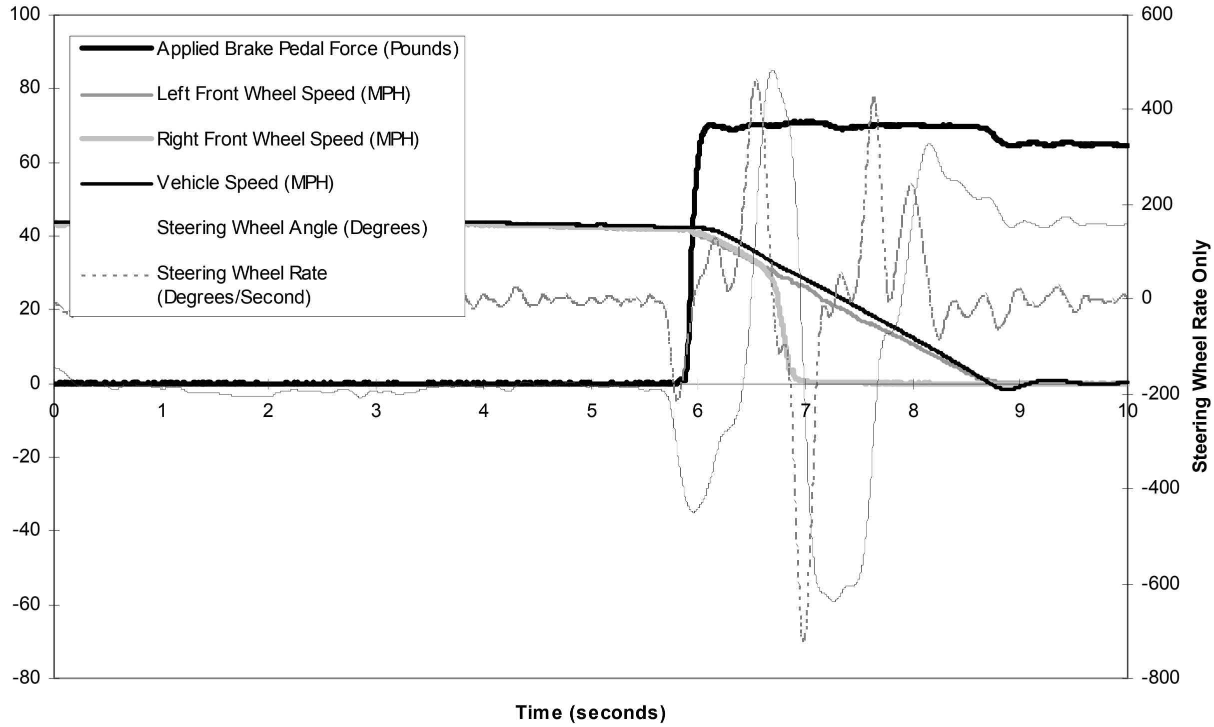

Figure 17. Successful avoidance maneuver with conventional brakes in which the subject steered left around the incursion vehicle.

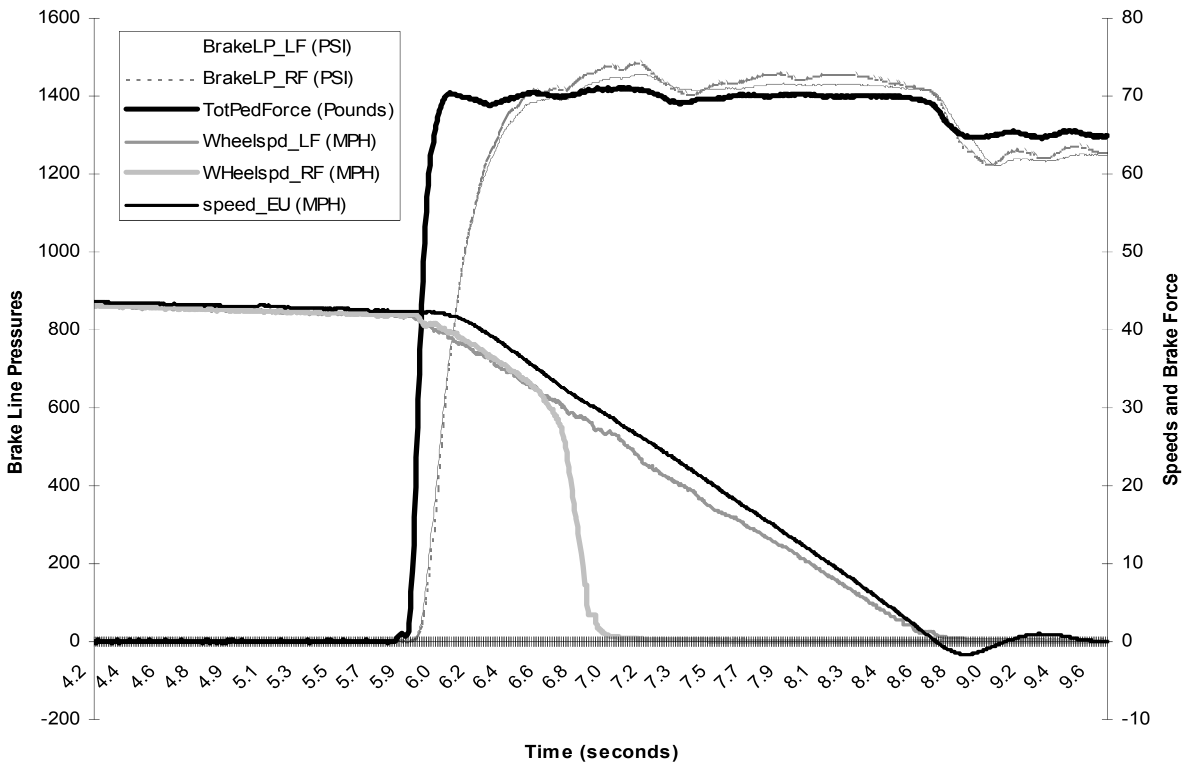

Figure 18. Brake line pressure and wheel speed data illustrating lockup of the right front wheel.

Figure 19 is an example of a successful avoidance maneuver in which a subject who was in the ABS condition steered left and braked simultaneously to maneuver the vehicle to avoid a crash with the incursion vehicle (time of incursion was 5.32 seconds).

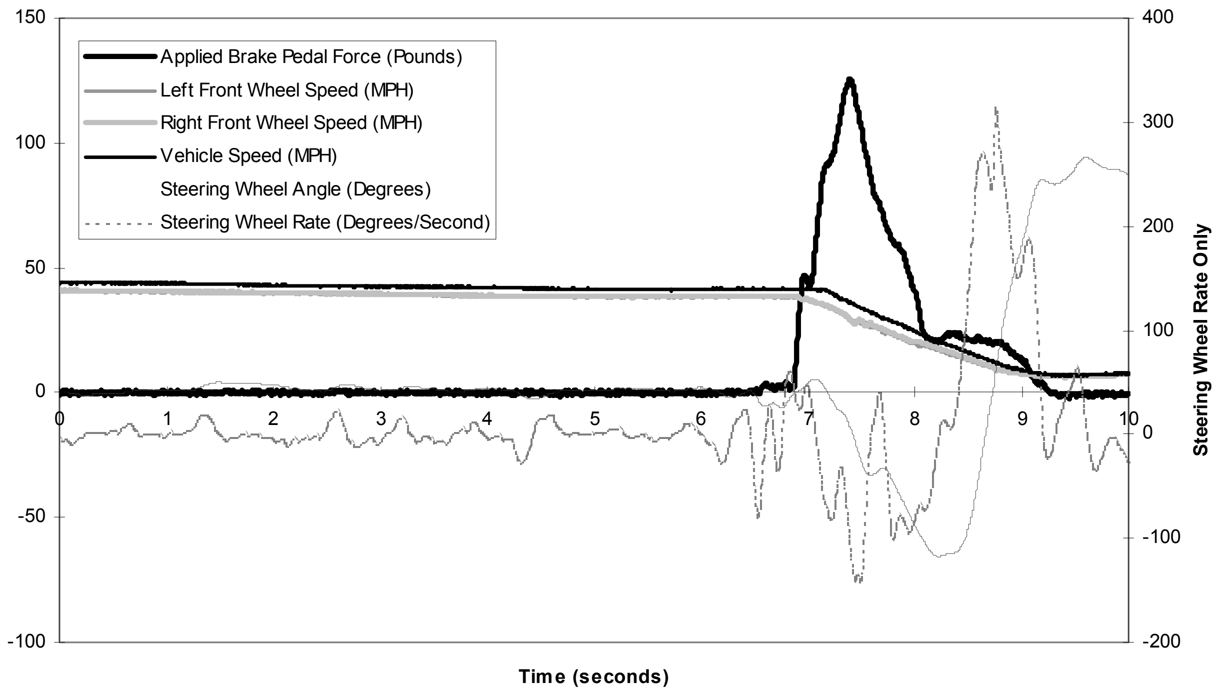

Figure 19. Successful avoidance maneuver with ABS in which the subject steered left around the incursion vehicle.

Figure 20 shows, for the same case covered in Figure 19, individual wheel speed and brake line pressure channels to demonstrate evidence of ABS activation (time of incursion was 5.32 seconds). Rear brake line pressures were building during a period when the applied brake pedal force was decreasing from approximately 7.6 to 8.4 seconds on the graph's x-axis scale suggesting ABS activation.

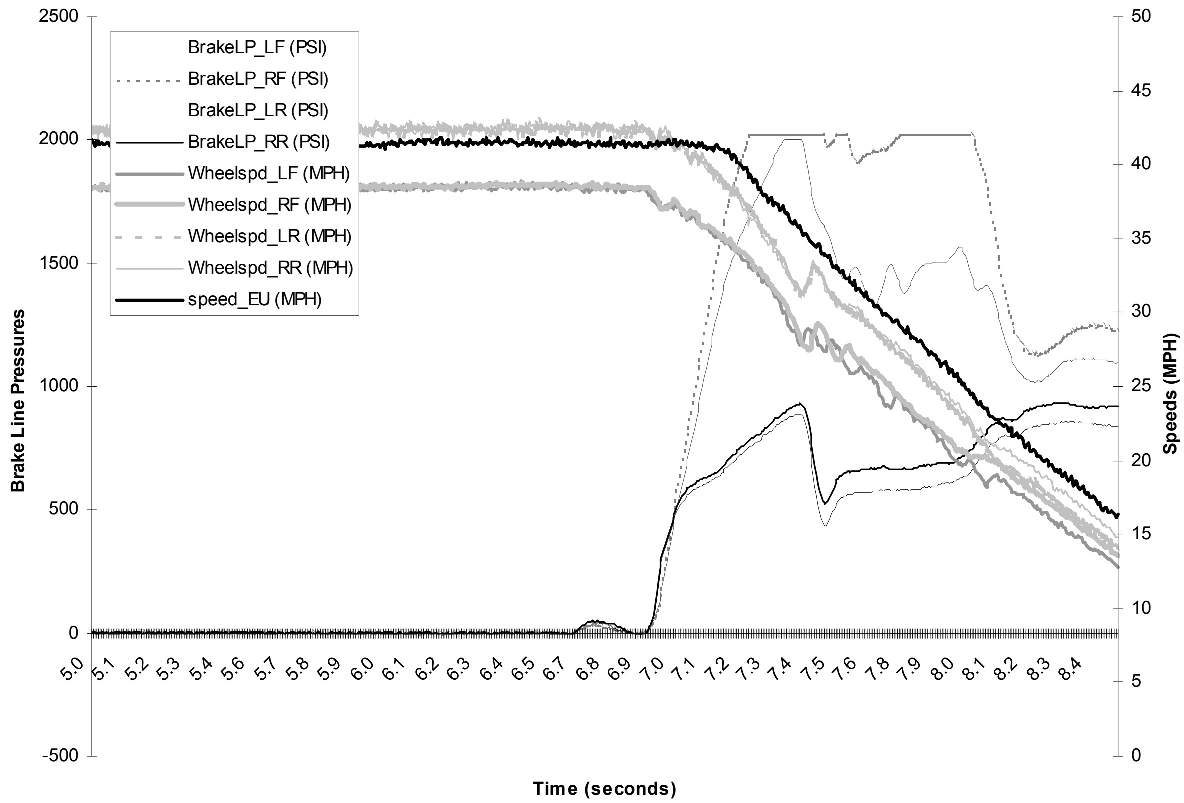

Figure 20. Brake line pressure and wheel speed data illustrating ABS activation.

Figure 21 is an example of a successful maneuver in which a subject driving with conventional brakes braked to a stop, without experiencing wheel lockup, to prevent a collision with the incursion vehicle (time of incursion was 4.51 seconds based on the above scale) This subject steered a small amount during the maneuver; however, these inputs were not primarily responsible for avoidance of the crash since the subject was able to brake to a stop.

Figure 22 is an example of a successful maneuver in which a subject driving with ABS braked to the point of ABS activation and came to a complete stop, thus preventing a collision with the incursion vehicle. This subject also steered a small amount during the crash avoidance maneuver; however, these inputs were not primarily responsible for avoidance of the crash.

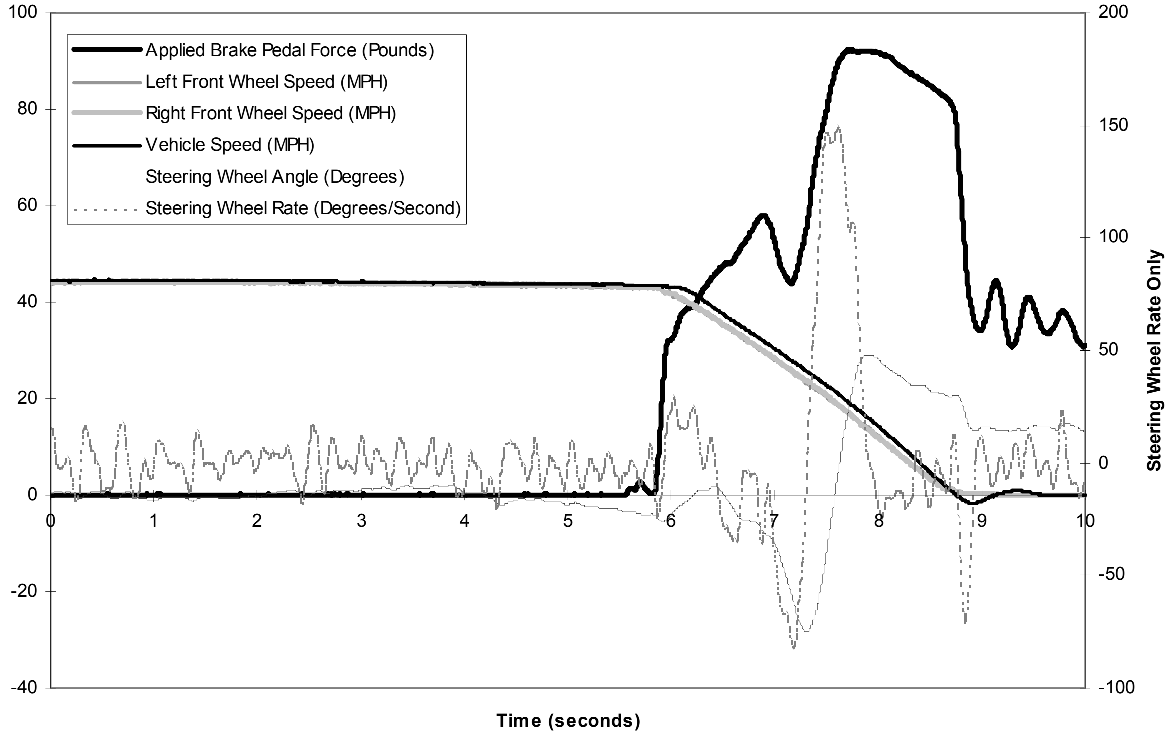

Figure 21. Successful avoidance maneuver with conventional brakes in which the subject braked the vehicle to a stop.

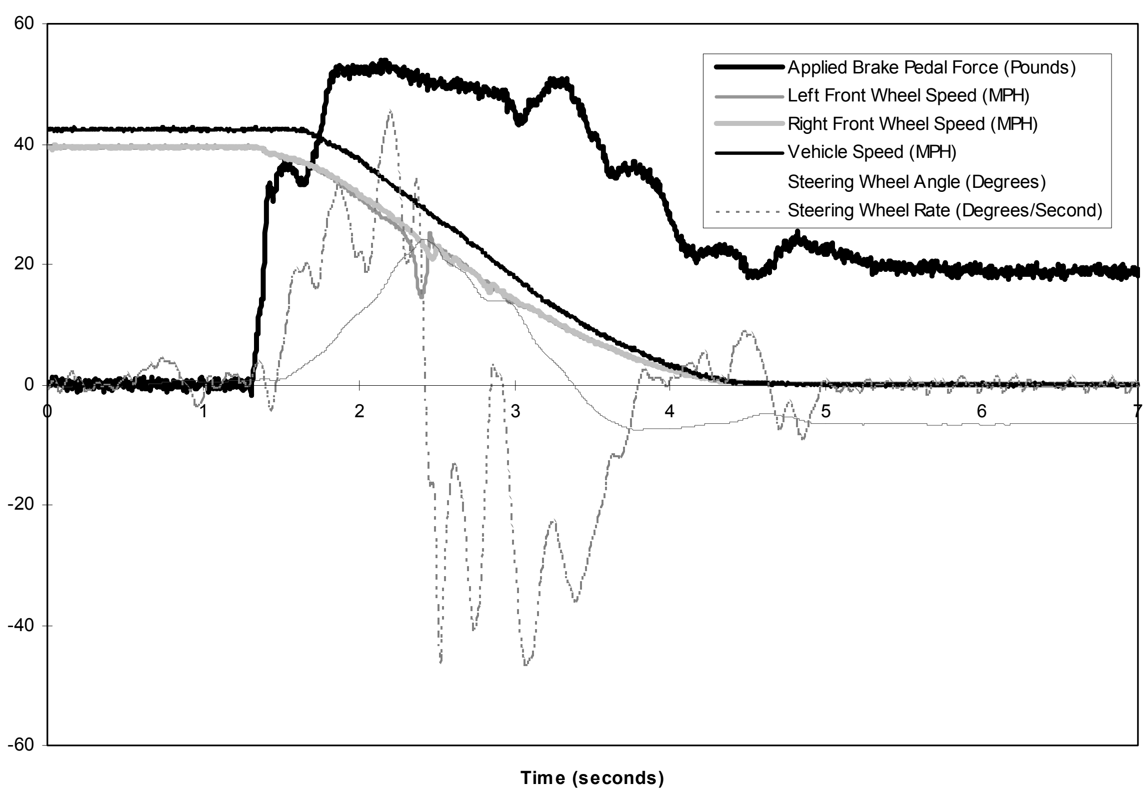

Figure 22. Successful avoidance maneuver with ABS in which the subject braked the vehicle to a stop.

Initial Steer to Initial Brake Transition Time by Brake System. For those subjects who steered first and then applied the brakes during the crash avoidance maneuver, the mean time from initial steering input to initial brake application did not differ significantly by brake system. Results for mean initial steer to initial brake transition time are shown in Table 20.

Initial Brake to Initial Steer Transition Time by Brake System. For those subjects who braked first and then steered during the crash avoidance maneuver, the mean time from initial brake input to initial steering input did not differ significantly by brake system. Results for mean initial brake to initial steer transition time are shown in Table 20.

Table 20. Transition Time Measures by Brake System. (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	BRAKE SYSTEM	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Initial Steer to Initial Brake Transition Time (s)	Conv.	32	0.22	0.20	0.02	0.79	0.4967	6	0.19	0.13	0.07	0.41	0.4474
	ABS	62	0.25	0.27	0.00	1.44		21	0.24	0.24	0.02	1.00	
Initial Brake to Initial Steer Transition Time (s)	Conv.	28	0.48	0.43	0.01	1.59	0.7494	10	0.50	0.56	0.05	1.79	0.2919
	ABS	59	0.61	0.66	0.02	3.16		15	0.34	0.25	0.04	0.83	

Initial Steering Input Direction by Brake System. Results for initial steering input direction by brake system and pavement condition are provided in Table 21.

Avoidance Steering Input Direction by Brake System. Results for avoidance steering input direction by brake system and pavement condition are provided in Table 21.

Table 21. Percentage of responses for steering input direction by pavement condition.

TYPE OF STEERING INPUT	DIRECTION OF STEERING INPUT	Dry		Wet	
		Conventional (64 subjects)	ABS (128 subjects)	Conventional (17 subjects)	ABS (36 subjects)
Initial Steering Input (%)	Left	56	66	53	75
	Right	38	27	41	25
	None	6	7	6	0
Avoidance Steering Input (%)	Left	81	73	76	75
	Right	13	20	18	25
	None	6	7	6	0

4.3.4. Steering Behavior by Brake System

Results for steering behavior as a function of brake system are summarized in Tables 22 and 23.

Table 22. Steering input measures by brake system (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System & Lockup / Activation	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Steering Input	Conventional – overall	60	1.64	0.47	1.01	2.98	0.7524	16	1.56	0.39	0.99	2.27	0.1732
	ABS - overall	121	1.65	0.62	0	4.26		36	1.39	0.42	0.69	2.71	
	Conventional - no lockup	44	1.65	0.47	1.01	2.98	0.6976	0	NA	NA	NA	NA	NA
	Conventional – lockup	16	1.62	0.47	1.02	2.98		16	1.56	0.39	0.99	2.27	
	ABS - no activation	82	1.73	0.64	0.68	4.26	0.6618	1	1.07				0.5783
	ABS - activation	39	1.50	0.56	0	3.10		35	1.40	0.42	0.69	2.71	
Initial Steering Input Magnitude (degrees)	Conventional – overall	60	28	44	6	276	0.4287	16	29	33	7	109	0.7868
	ABS - overall	119	29	28	6	129		36	32	26	7	95	
	Conventional - no lockup	44	21	21	6	109	0.0995	0	NA	NA	NA	NA	NA
	Conventional – lockup	16	46	77	6	276		16	29	33	7	109	
	ABS - no activation	81	31	27	7	129	0.2187	1	51				0.8254
	ABS - activation	38	25	30	6	113		35	32	26	7	95	
Avoidance Steering Input Magnitude (degrees)	Conventional – overall	60	61	52	6	271	0.4535	16	103	88	10	289	0.0095
	ABS - overall	120	49	38	2	197		36	61	46	7	209	
	Conventional - no lockup	44	49	32	6	146	0.0010	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	92	78	6	271		16	103	88	10	289	
	ABS - no activation	81	47	31	4	129	0.3531	1	51				0.7380
	ABS - activation	39	52	50	2	197		35	62	46	7	209	
	Conventional - lockup	16	92	78	6	271	0.0127	16	103	88	10	289	0.0748
	ABS - activation	39	52	50	2	197		35	62	46	7	209	
Avoidance Steering Input Range (degrees)	Conventional - overall	60	60	54	7	276	0.5250	16	102	107	7	400	0.0655
	ABS - overall	116	53	42	7	215		36	63	63	7	302	
	Conventional - no lockup	44	48	35	7	179	0.0002	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	94	79	7	276		16	102	107	7	400	
	ABS - no activation	78	53	38	8	215	0.3461	1	13				0.4396
	ABS - activation	38	55	48	7	175		35	65	64	7	302	
	Conventional - lockup	16	94	79	7	276	0.0351	16	102	107	7	400	0.0894
	ABS - activation	38	55	48	7	175		35	65	64	7	302	

Table 23. Steering input measures by brake system (Non-significant results denoted by shaded p-values.

MEASURE	Brake System & Lockup / Activation	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Maximum Steering Input	Conventional - overall	60	2.70	0.66	1.47	4.97	0.7608	16	3.37	1.31	1.70	5.85	0.0003
	ABS - overall	122	2.73	0.93	1.17	6.72		36	2.39	0.55	1.04	4.33	
	Conventional - no lockup	44	2.66	0.67	1.47	4.97	0.0784	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	2.82	0.62	1.55	4.12		16	3.37	1.31	1.70	5.85	
	ABS - no activation	82	2.80	0.88	1.19	6.72	0.8237	1	1.37				0.0564
	ABS - activation	40	2.61	1.02	1.17	5.99		35	2.42	0.53	1.04	4.33	
	Conventional - lockup	16	2.82	0.62	1.55	4.12	0.6862	16	3.37	1.31	1.70	5.85	0.0007
	ABS - activation	40	2.61	1.02	1.17	5.99		35	2.42	0.53	1.04	4.33	
Mean Maximum Steering Input Magnitude (degrees)	Conventional - overall	60	65	54	6	271	0.4385	16	106	85	10	289	0.0058
	ABS - overall	121	53	40	8	221		36	62	44	7	209	
	Conventional - no lockup	44	52	34	6	146	0.0002	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	100	80	7	271		16	106	85	10	289	
	ABS - no activation	82	51	31	9	129	0.2768	1	51				0.6524
	ABS - activation	39	57	53	8	221		35	63	44	7	209	
	Conventional - lockup	16	100	80	7	271	0.0465	16	106	85	10	289	0.0082
	ABS - activation	39	57	53	8	221		35	63	44	7	209	
Mean Maximum Steering Input Rate (degrees per second)	Conventional - overall	60	296	218	30	982	0.5701	17	255	183	33	643	0.8649
	ABS - overall	122	246	189	30	1159		36	313	258	35	1335	
	Conventional - no lockup	44	279	213	30	982	0.1050	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	341	232	39	721		16	268	181	33	643	
	ABS - no activation	82	241	160	30	640	0.9912	1	211				0.6620
	ABS - activation	40	256	240	33	1159		35	316	262	35	1335	
	Conventional - lockup	16	341	232	39	721	0.4834	16	268	181	33	643	0.9841
	ABS - activation	40	256	240	33	1159		35	316	262	35	1335	
Mean First Lane Recovery Steering Input Range (degrees)	Conventional - overall	59	101	69	5	284	0.5400	16	107	91	11	324	0.3490
	ABS - overall	107	100	71	7	418		36	100	68	7	302	
	Conventional - no lockup	43	96	60	5	227	0.4047	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	115	91	6	284		16	107	91	11	324	
	ABS - no activation	72	100	54	9	241	0.1539	1	83				0.6963
	ABS - activation	35	100	98	7	418		35	100	68	7	302	
Total Number of Steering Inputs During the Avoidance Maneuver	Conventional - overall	60	4.2	1.3	1	8	0.2105	16	4.8	2.2	2	11	0.4557
	ABS - overall	119	3.8	1.5	1	7		36	4.6	1.3	2	8	
	Conventional - no lockup	44	4.2	1.3	1	8	0.7139	0	NA	NA	NA	NA	NA
	Conventional - lockup	16	4.2	1.2	2	7		16	4.8	2.2	2	11	
	ABS - no activation	81	3.8	1.5	1	7	0.5867	1	5				0.8548
	ABS - activation	38	3.9	1.6	1	7		35	4.6	1.3	2	8	

Time to Initial Steering Input by Brake System. Results for time to initial steering input as a function of brake system are presented in Table 22. Results are also listed for this measure as a function of ABS activation and wheel lockup with conventional brakes in Table 22. For wet pavement, no comparison could be made for this measure as a function of wheel lockup because the one subject who did not lock the wheels with conventional brake also did not steer.

Initial Steering Input Magnitude by Brake System. Results for time to initial steering input as a function of brake system are presented in Table 22.

Avoidance Steering Input Magnitude by Brake System. Data for the mean magnitude of the avoidance steering input are summarized in Table 22. Figures 23 and 24 contain frequency distributions for avoidance steering input magnitudes by brake system for dry and wet pavement conditions, respectively.

The mean avoidance steering input value was significantly smaller ($p = 0.0127$) for subjects in the ABS condition that activated ABS than for subjects in the conventional brake system condition who experienced wheel lockup. This trend was also seen for these groups on wet pavement, but the difference was not significant ($p = 0.0748$).

Avoidance Steering Input Range by Brake System. The mean avoidance steering input ranges observed as a function of brake system and pavement condition are listed in Table 22. The mean avoidance steering input ranges were nearly significantly different ($p = 0.0655$) for wet pavement as a function of brake system. Figure 24 shows the frequency distribution of avoidance steering input ranges for subjects with ABS according to whether or not they activated ABS or locked wheels with conventional brakes during their crash avoidance maneuver.

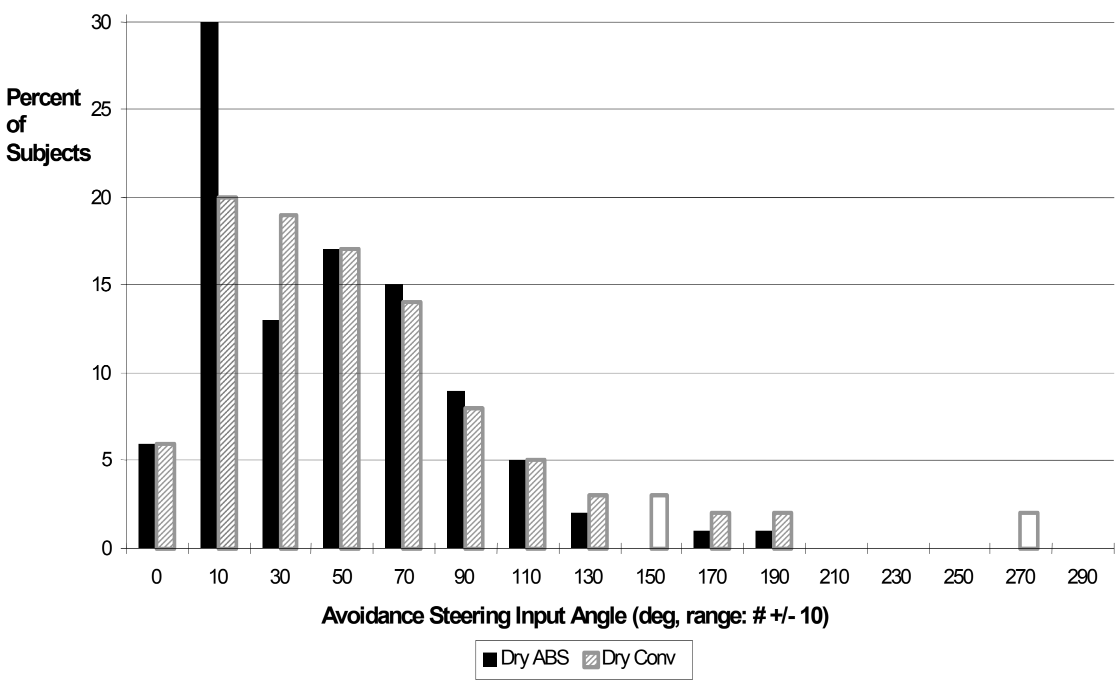

Figure 23. Frequency distribution of avoidance steering input magnitudes by brake system for dry pavement.

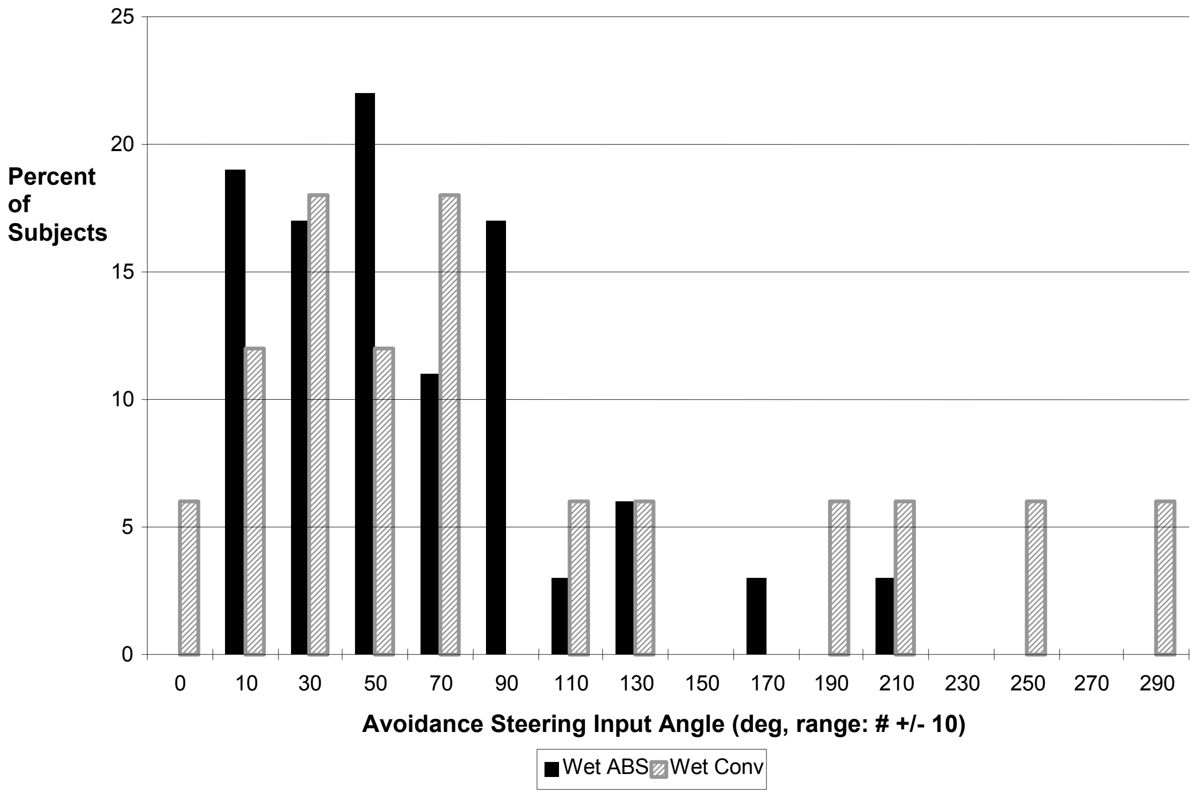

Figure 24. Frequency distribution of avoidance steering input magnitudes by brake system for wet pavement.

Comparing mean avoidance steering input range on dry pavement for subjects who activated ABS versus subjects in the conventional brake system condition who experienced wheel lockup showed that the subjects in the ABS group had a significantly smaller mean range than those in the conventional brake system group ($p = 0.0351$). This comparison did not show a significant effect for wet pavement ($p = 0.0894$).

Time to Maximum Steering Input by Brake System. Table 23 lists results for the time from initiation of the incursion vehicle's motion until the time subjects applied their maximum steering inputs. Table 23 also summarizes results for time to maximum steering input by brake system as a function of wheel lockup with conventional brakes and ABS activation. The subject in the wet pavement study, who did not lock the wheels, also did not steer.

Comparing mean time to maximum steering input on dry pavement for subjects who activated ABS versus subjects in the conventional brake system condition who experienced wheel lockup revealed no significant difference ($p = 0.6862$). The same comparison for wet pavement showed that subjects in the ABS group reached their maximum steering input in significantly less time (2.42 seconds) than those in the conventional brake system group (3.37 seconds)($p = 0.0007$).

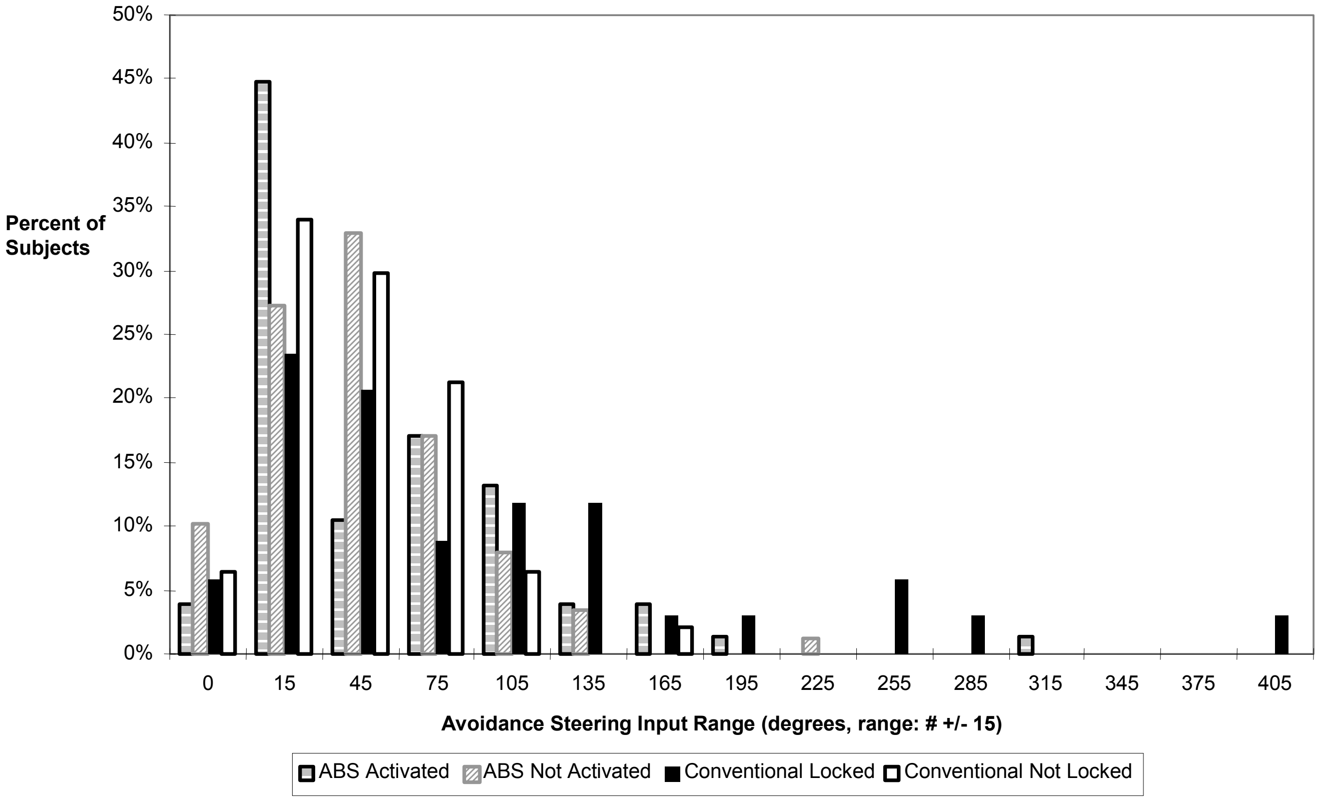

Figure 25. Frequency distribution of avoidance steering input range by brake system as a function of whether ABS was activated or whether wheels were locked with conventional brakes for wet pavement.

Maximum Steering Input Magnitude by Brake System. The mean maximum steering input magnitudes are listed in Table 23. For conventional brakes (lockup and no lockup) and ABS (activation and no activation) the values were not significantly different for dry pavement, (p = 0.4385), but were significantly different for wet pavement (p = 0.0058).

Comparing subjects who experienced wheel lockup with conventional brakes versus those who activated ABS in the ABS condition on dry pavement, the mean maximum steering input magnitude for subjects in the ABS group was significantly smaller (57 degrees) than for the subjects in the conventional brake system group (100 degrees)(p = 0.0465). This comparison also showed a significant difference on wet pavement where the mean maximum steering input magnitude for ABS subjects (63 degrees) was again smaller than that for conventional brake system subjects (106 degrees)(p = 0.0082).

Maximum Steering Input Range by Brake System. Figure 26 shows the frequency distribution across both pavement conditions for maximum steering wheel input ranges by brake system and whether or not ABS was activated or whether wheels were locked in the conventional brake system case.

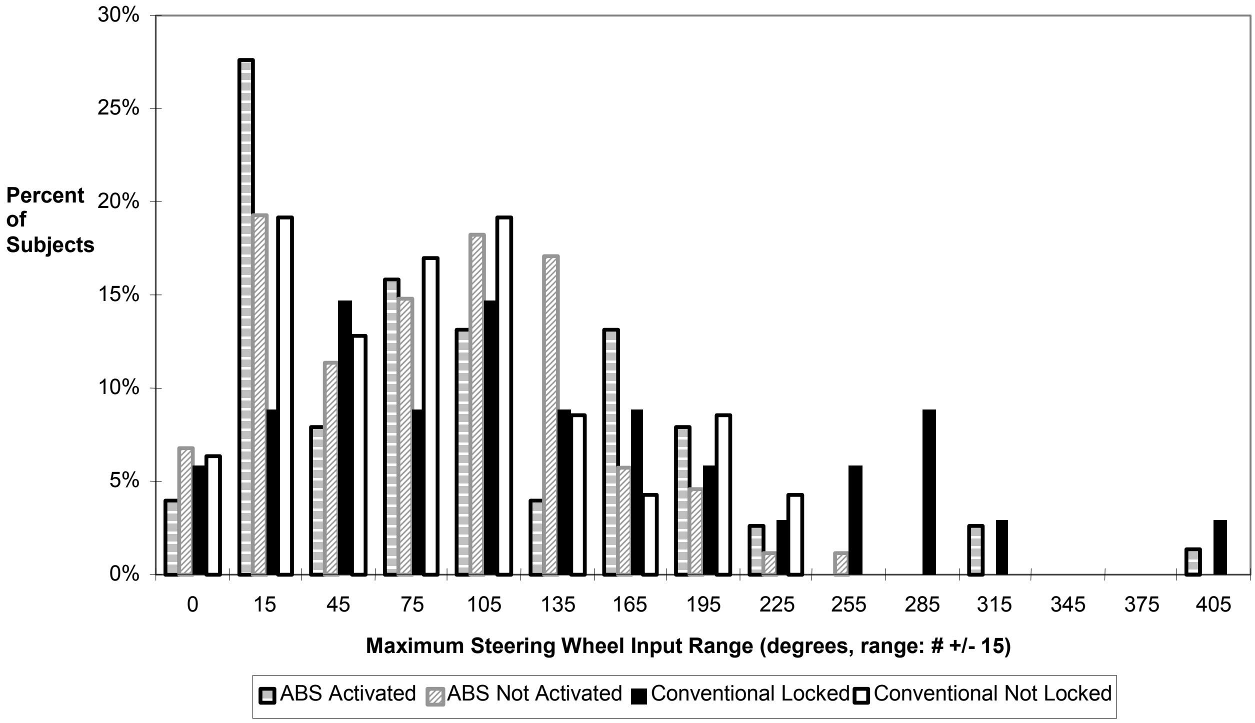

Figure 26. Frequency distribution of maximum steering wheel input range by brake system and whether ABS was activated or whether wheels were locked in the conventional brake system condition.

Maximum Steering Input Rate by Brake System. Data for the mean maximum steering rate during the avoidance maneuver is shown in Table 23. Figures 27 and 28 show the frequency distributions of maximum steering rates by brake system for dry and wet pavement conditions, respectively.

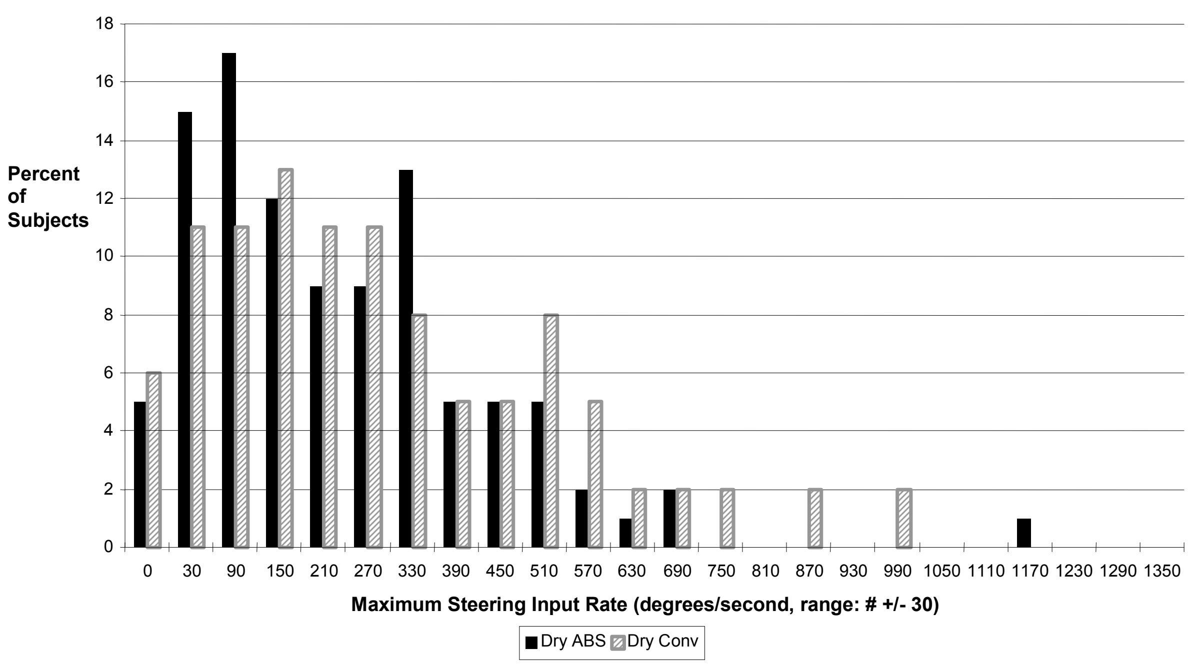

Figure 27. Frequency distribution of maximum steering input rates by brake system for dry pavement.

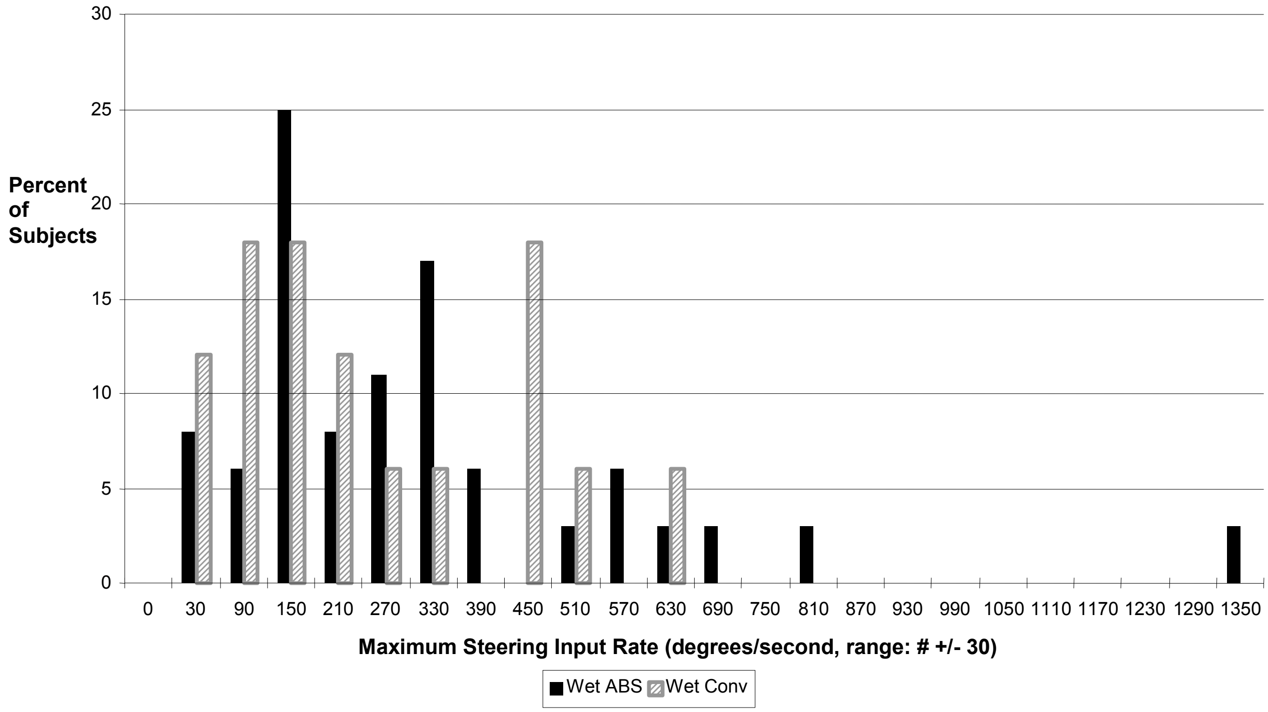

Figure 28. Frequency distribution of maximum steering input rates by brake system for wet pavement.

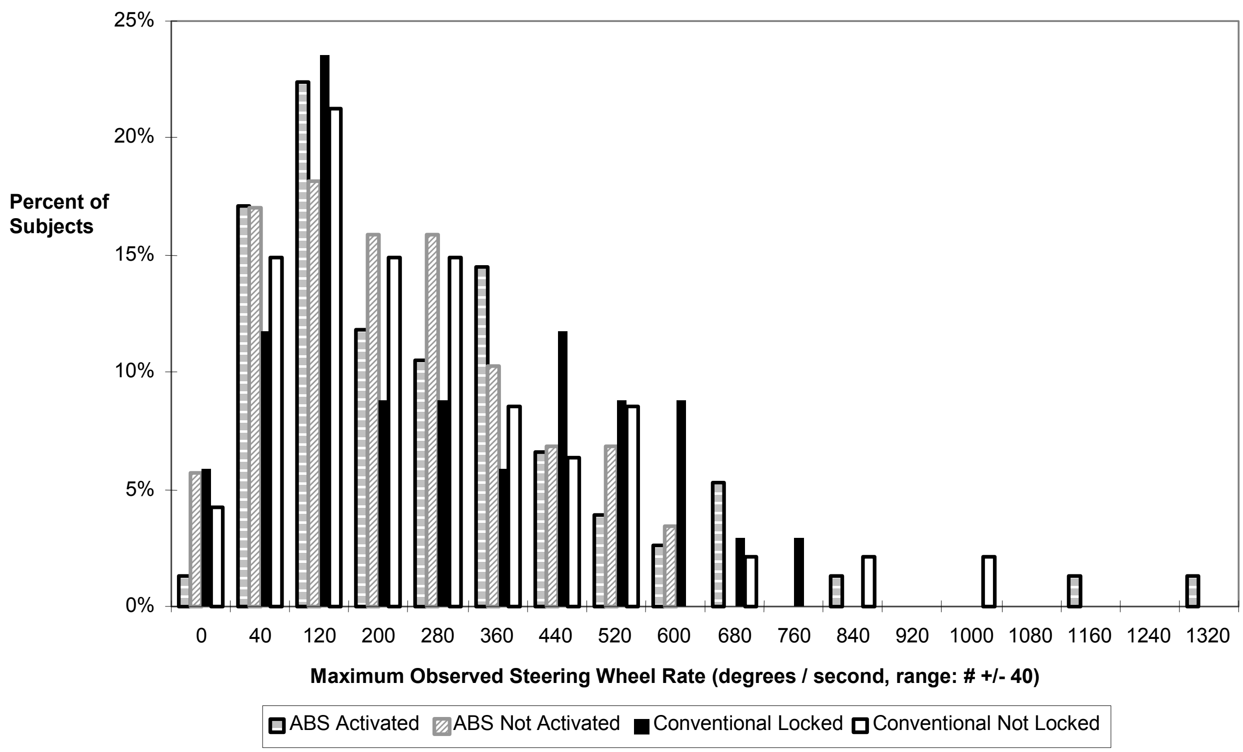

Figure 29. Frequency distribution of maximum steering wheel input rate by brake system and whether ABS was activated or whether wheels were locked with conventional brakes.

Figure 30 shows the frequency distributions of maximum steering wheel input rate by brake system and whether or not ABS was activated or whether wheels were locked in the conventional brake system case.

Comparing subjects who experienced wheel lockup with conventional brakes versus those who activated ABS in the ABS condition on dry pavement, the mean maximum steering input rate for subjects in the ABS group was less (256 degrees per second) than for the subjects in the conventional brake system group (341 degrees per second). However this result was not statistically significant ($p = 0.4834$). The values in this comparison also did not show a significant difference for wet pavement ($p = 0.9841$).

First Lane Recovery Steering Input Range by Brake System. The mean values of subjects' first lane recovery steering input for a variety of conditions are listed in Table 23. Figure 30 shows the frequency distribution of first lane recovery steering input ranges for subjects with ABS as a function of whether or not ABS was activated and subjects with conventional brakes as a function of whether or not wheels were locked. Values for the mean first lane recovery steering input range as a function of wheel lockup did not differ significantly for dry pavement ($p = 0.4047$).

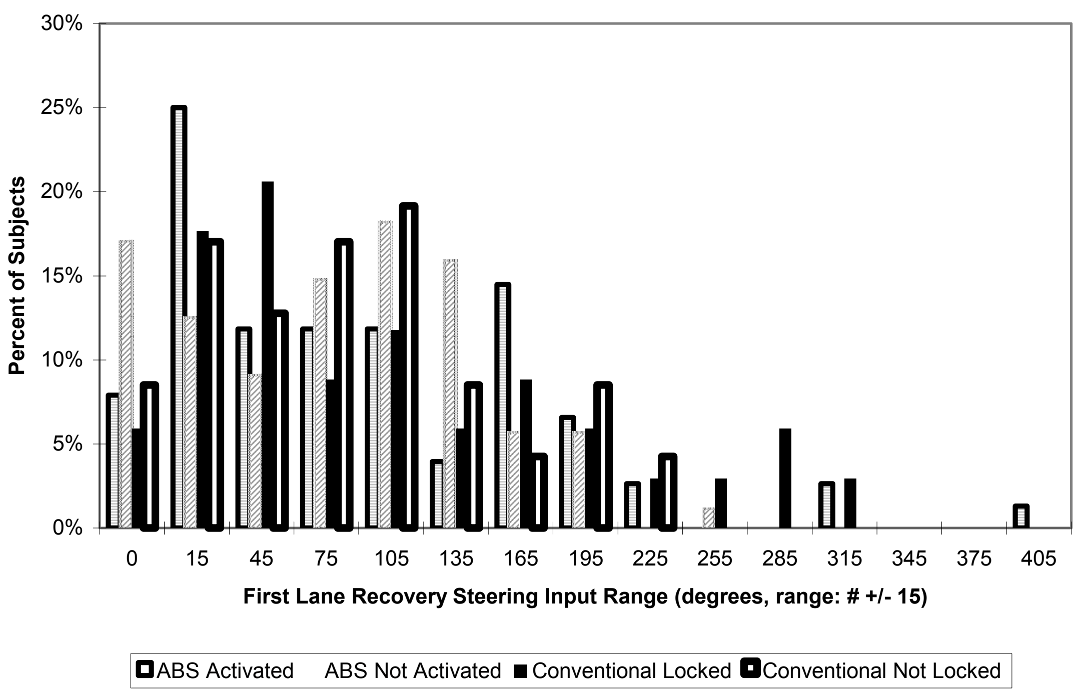

Figure 30. Frequency distribution of first lane recovery steering input range by brake system and whether ABS was activated or whether wheels were locked with conventional brakes.

Total Number of Steering Inputs Made During the Avoidance Maneuver by Brake System. The results for total number of steering inputs observed during the crash avoidance maneuver are listed in Table 23.

4.3.5. Braking Behavior by Brake System

Measures of braking behavior observed in response to the incursion scenario are briefly summarized in Table 24 and are discussed in more detail below.

Table 24. Braking input measures by brake system (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System & Lockup / Activation	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time to Initial Brake Input (s)	Conventional - overall	64	1.51	0.29	0.84	2.34	0.7454	16	1.51	0.35	1.05	2.38	0.6147
	ABS - overall	127	1.49	0.30	0.61	2.29		36	1.38	0.33	0.88	2.41	
	Conventional - no lockup	46	1.56	0.32	0.84	2.34	0.1077	1	2.38				0.0099
	Conventional - lockup	18	1.41	0.19	1.04	1.88		15	1.45	0.27	1.05	1.87	
	ABS - no activation	86	1.52	0.32	0.61	2.29	0.4514	1	1.40				0.8314
	ABS -activation	41	1.43	0.25	1.02	2.05		35	1.38	0.33	0.88	2.41	
Throttle to Brake Application Transition Time (s)	Conventional - overall	62	0.31	0.17	0.10	0.93	0.5449	16	0.31	0.31	0.01	1.34	0.3083
	ABS - overall	125	0.30	0.18	-0.14	0.79		35	0.30	0.29	0.01	1.27	
	Conventional - no lockup	46	0.34	0.18	0.13	0.93	0.0299	1	1.34				0.0001
	Conventional - lockup	16	0.25	0.10	0.10	0.50		15	0.24	0.14	0.01	0.62	
	ABS - no activation	85	0.33	0.19	-0.14	0.79	0.0259	1	0.42				0.9101
	ABS -activation	40	0.25	0.14	-0.05	0.79		34	0.30	0.29	0.01	1.27	
Throttle to Maximum Brake Application Time (s)	Conventional - overall	63	1.17	0.71	0.24	3.82	0.5742	16	1.36	0.96	0.54	4.18	0.4927
	ABS - overall	127	1.14	0.58	0.28	4.04		35	1.08	0.50	0.29	2.15	
	Conventional - no lockup	46	1.05	0.55	0.24	2.30	0.0257	1	4.18				0.0008
	Conventional - lockup	17	1.50	0.96	0.49	3.82		15	1.17	0.61	0.54	3.18	
	ABS - no activation	86	1.11	0.52	0.29	3.51	0.1666	1	1.05				0.7105
	ABS -activation	41	1.20	0.69	0.28	4.04		34	1.09	0.51	0.29	2.15	
Time to Maximum Brake Pedal Force (s)	Conventional - overall	64	2.33	0.54	1.12	4.14	0.4263	17	2.55	0.86	1.96	5.22	0.1746
	ABS - overall	127	2.28	0.42	1.30	3.51		36	2.16	0.47	1.34	3.17	
	Conventional - no lockup	46	2.27	0.46	1.12	3.40	0.1641	1	5.22				0.0002
	Conventional - lockup	18	2.49	0.70	1.67	4.14		16	2.39	0.53	1.96	4.18	
	ABS - no activation	86	2.27	0.42	1.30	3.51	0.0257	1	2.03				0.8558
	ABS-activation	41	2.31	0.43	1.35	3.37		35	2.17	0.48	1.34	3.17	
Mean Maximum Brake Pedal Force (lbs)	Conventional - overall	64	62	33	9	182	0.8852	17	59	27	12	110	0.4730
	ABS - overall	127	65	30	3	188		36	72	45	12	240	
	Conventional - no lockup	46	51	24	9	150	0.0001	1	12				0.0527
	Conventional - lockup	18	91	36	49	182		16	62	24	31	110	
	ABS - no activation	86	54	24	3	170	0.0001	1	12				0.2469
	ABS-activation	41	87	30	51	188		35	74	45	13	240	
Mean Brake Pedal Application Duration (s)	Conventional - overall	64	1.99	1.47	0.01	8.90	0.7587	17	3.23	2.52	0.21	7.70	0.0404
	ABS - overall	127	2.20	1.13	0.01	5.39		36	2.08	1.64	0.11	6.09	
	Conventional - no lockup	46	1.78	1.17	0.01	4.94	0.8238	1	3.46				0.1982
	Conventional - lockup	18	2.52	2.00	0.01	8.90		16	3.22	2.60	0.21	7.70	
	ABS - no activation	86	2.07	1.09	0.01	4.66	0.0139	1	0.11				0.4936
	ABS -activation	41	2.46	1.18	0.05	5.39		35	2.13	1.63	0.15	6.09	

Time to Initial Brake Input (Brake Reaction Time) by Brake System. Results for time to initial brake input are listed in Table 24. The mean brake reaction time for those in the conventional brake system condition showed a significant effect of wheel lockup ($p = 0.0099$) for wet pavement. However, this result involved the comparison of a large group of subjects who locked the wheels with conventional brakes (mean brake reaction time of 1.45 seconds) against a single subject who did not lock the wheels.

Throttle to Brake Application Transition Time by Brake System. The mean throttle to brake transition time values observed are summarized in Table 24.

Throttle to Maximum-Brake Application Transition Time by Brake System. Table 24 summarizes the results for mean throttle to maximum-brake application transition time.

Time to Maximum Brake Input by Brake System. Values for mean time to maximum brake input are listed in Table 24.

Maximum Brake Pedal Force by Brake System. Results for maximum brake pedal force as a function of brake system are listed in Table 24. Figures 31 and 32 show the frequency distributions for maximum brake forces by brake system and pavement condition.

On dry pavement, ABS activation was found to have a significant effect on the mean maximum applied brake pedal force wherein those who activated ABS had a higher mean maximum applied brake pedal force (87 lbs) than did those who did not activate ABS (54 lbs)($p = 0.0001$).

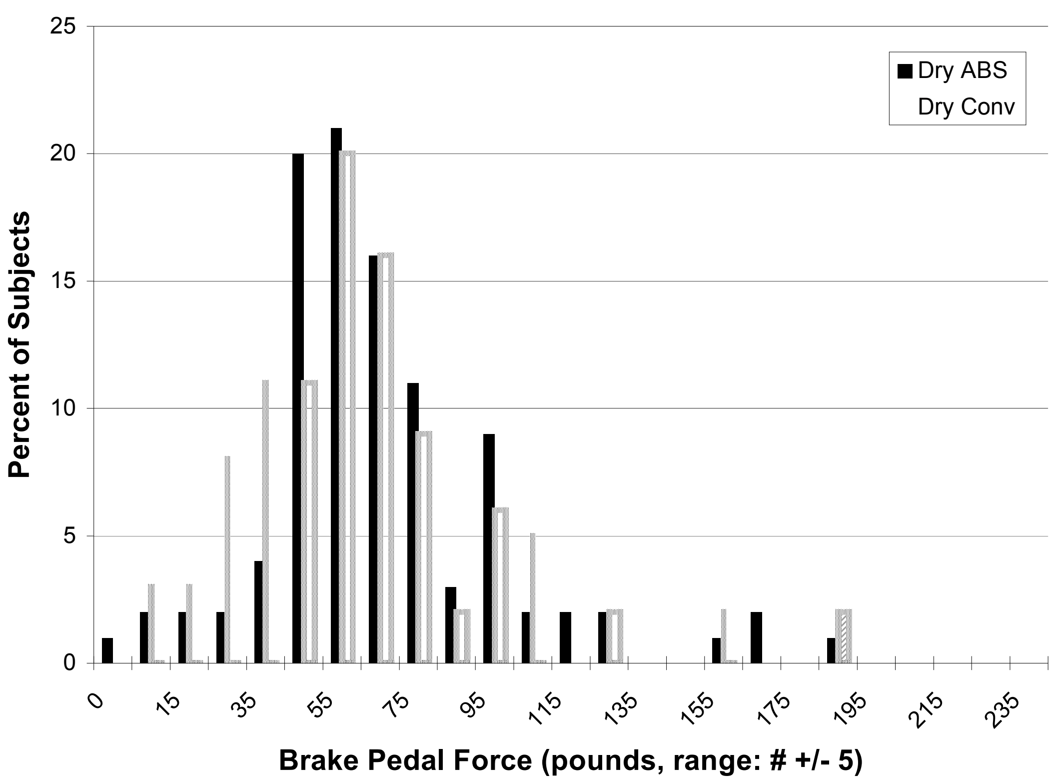

Figure 31. Frequency distribution of maximum brake pedal force by brake system for dry pavement.

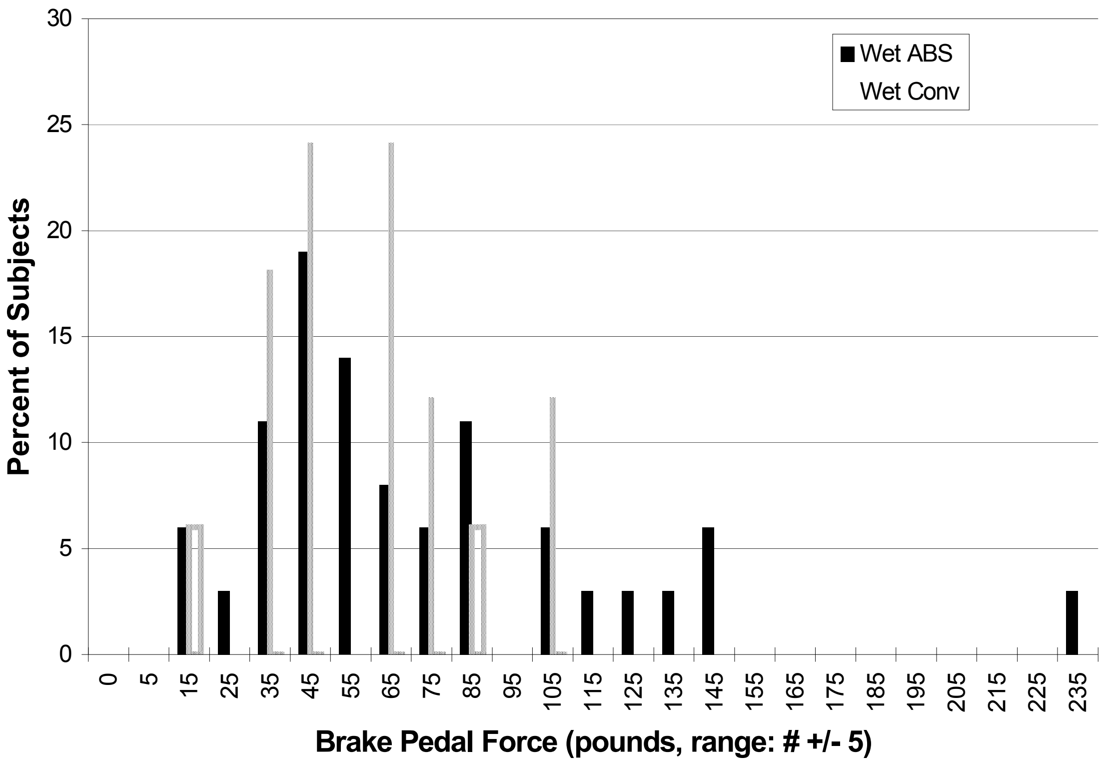

Figure 32. Frequency distribution of maximum brake pedal force by brake system for wet pavement.

On wet pavement, this trend of higher observed brake pedal force values for those who activated ABS was also seen, although there was no significant effect for this pavement condition ($p = 0.2469$). These findings show that, as expected, activating ABS requires a relatively higher applied pedal force. Similarly, higher mean maximum brake pedal force values were found for those who locked the wheels with conventional brakes than for those who did not experience lockup on both dry ($p = 0.0001$) and wet pavement ($p = 0.0527$). A summary of these results is presented in Table 24.

Brake Pedal Application Duration by Brake System. Table 24 provides a breakdown of values obtained for mean brake pedal application durations observed by brake system and pavement condition. Figures 33 and 34 show the frequency distributions of subjects' brake application durations by brake system for dry and wet pavement conditions, respectively.

Based on an examination of the video recordings of each subject's experience of the intersection incursion scenario from both the dry and wet pavement experiments, no evidence was observed of subjects either pulling their foot off of the brake pedal due to being startled by ABS pedal feedback, or attempting to "pump" the brake pedal with ABS.

Wheel Lockup and ABS Activations by Brake System. ABS brake activations and conventional wheel lockup percentages were consistent with respect to pavement condition. In the dry pavement study, nearly one-third of the subject population activated ABS or locked wheels with conventional brakes. In the wet pavement study, the percentages were near 100 percent. Table 25 provides data for the percent of ABS activations and instances of conventional wheel lockup by brake system.

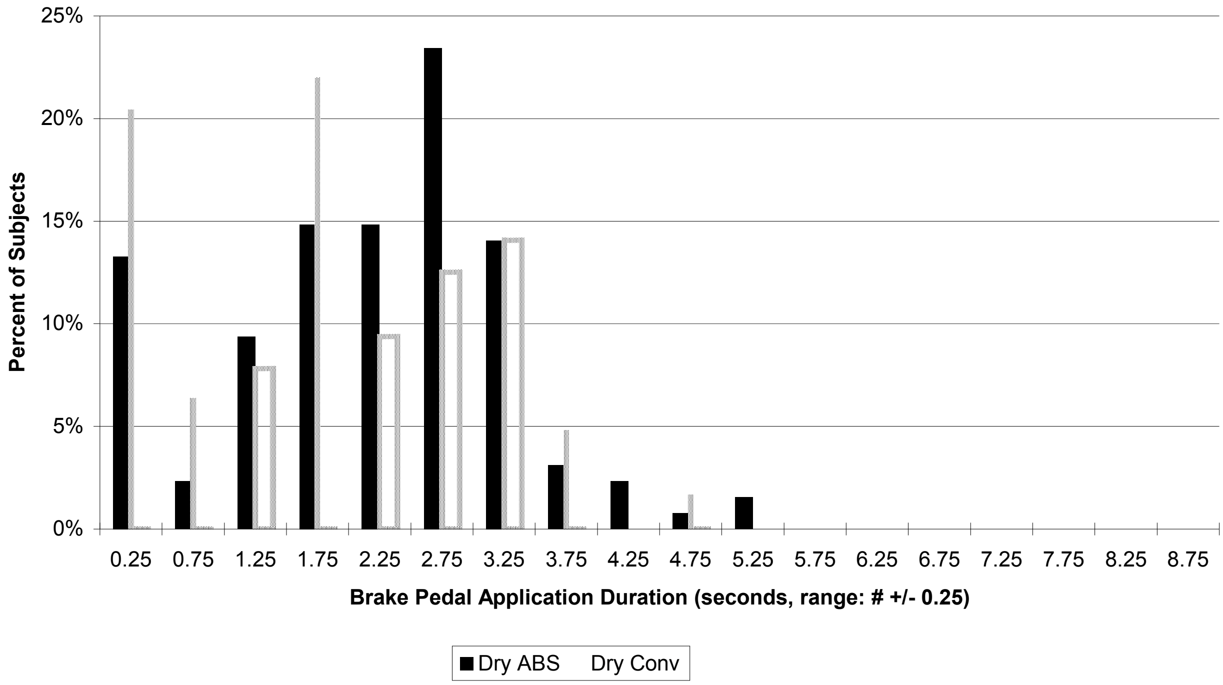

Figure 33. Brake pedal application duration frequency by brake system for dry pavement.

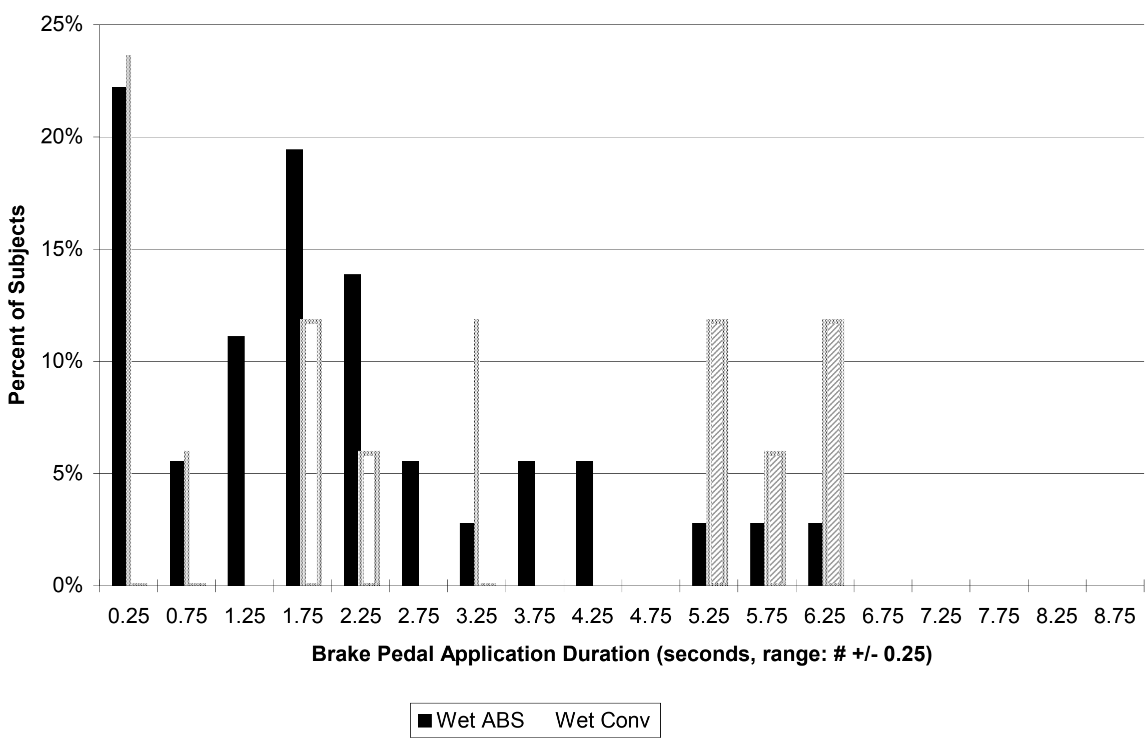

Figure 34. Brake pedal application duration frequency by brake system for wet pavement.

Table 25. Percent ABS activations and conventional wheel lockups by brake system.

BRAKE SYSTEM	Dry		Wet	
	% Activated ABS or Locked Wheels	P-value	% Activated ABS or Locked Wheels	P-value
Conventional	28	0.5802	94	0.5798
ABS	32		97	

Missed Brake Pedal Applications by Brake System. Review of the video of the subjects' responses to the intersection incursion produced interesting observations about subjects' brake applications. A surprising number of subjects "missed" the brake pedal in their first attempt to apply the brakes. Some subjects missed the pedal more than once. No subjects missed the brake pedal more than twice. In addition, some subjects braked with the left foot or both feet. The percentages of missed brake pedal application attempts overall and by brake system were surprisingly large, as shown in Table 26. However, no significant differences by brake system were found. Twelve subjects for whom video data was not successfully recorded were not included in this analysis.

Table 26. Percentage of brake pedal misses and braking application techniques by brake system.

BRAKE SYSTEM	Percent of Subjects Who Missed Brake Pedal One Time			Percent of Subjects Who Missed Brake Pedal Two Times			Percent of Subjects Who Used a Non-Standard Brake Application Technique		
	Dry	Wet	Both	Dry	Wet	Both	Dry	Wet	Both
Conventional	32	0	25	0	0	0	7	0	5
ABS	25	13	22	6	0	5	8	3	7

4.3.6. Deceleration by Brake System

An analysis was conducted to determine the average maximum deceleration achieved by subjects as a function of brake system. Overall (across both pavement conditions), the mean maximum deceleration was 0.67 g (SD 0.25, max 1.15, min 0.004) for subjects with ABS and 0.65 g (SD 0.25, max 1.07, min 0.06) for subjects with conventional brakes. These values were not significantly different ($p = 0.5770$). These data were also examined by pavement condition and wheel lockup or ABS activation as presented in Table 27.

Table 27. Deceleration by brake system and wheel lockup / ABS activation.

Brake System & Lockup / ABS Activation	Dry						Wet					
	N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Conventional – Overall	64	0.70	0.25	0.06	1.07	0.7897	17	0.45	0.12	0.004	0.67	0.7690
ABS - Overall	128	0.73	0.24	0.01	1.15		36	0.45	0.12	0.004	0.67	
Conventional - No Lockup	46	0.60	0.23	0.06	1.07	--	1	0.25				--
Conventional - Lockup	18	0.94	0.09	0.78	1.06		16	0.46	0.06	0.37	0.61	
ABS - No Activation	87	0.64	0.21	0.03	1.10	--	1	0.004				--
ABS - Activation	41	0.91	0.20	0.01	1.15		35	0.46	0.09	0.17	0.67	

4.3.7. Lateral Acceleration by Brake System

Mean maximum lateral acceleration results are presented in Table 28.

Table 28. Lateral Acceleration by brake system and wheel lockup / ABS activation.

Brake System & Lockup / ABS Activation	Dry						Wet					
	N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Conventional - Overall	64	0.26	0.18	0.04	0.67	0.2722	17	0.21	0.12	0.01	0.41	0.3456
ABS - Overall	128	0.25	0.18	0.03	0.73		36	0.25	0.13	0.01	0.51	
Conventional - No Lockup	46	0.28	0.18	0.04	0.67	0.8903	1	0.22				0.8408
Conventional - Lockup	18	0.22	0.17	0.05	0.64		16	0.21	0.12	0.01	0.41	
ABS - No Activation	87	0.26	0.18	0.03	0.70	0.1746	1	0.38				0.3675
ABS - Activation	41	0.24	0.20	0.03	0.73		35	0.24	0.13	0.01	0.51	

4.3.8. Road Departures by Brake System

Full Road Departures by Brake System. In the dry pavement study, 2 subjects out of 192 drove completely off the road (all four wheels) during the avoidance maneuver. Both of these subjects who experienced road departures were in the ABS condition (128 subjects) and one of them activated ABS during the crash avoidance maneuver. None of the 64 subjects who had conventional brakes drove completely off the road during the avoidance maneuver. In the wet pavement study, no subject drove completely off the road.

Partial Road Departures by Brake System. In addition, three partial road departures were also observed. In the dry pavement study, one subject driving with ABS and another driving with conventional brakes both experienced two-wheel road departures. In the wet pavement study, only one subject, who happened to be in the conventional brake system condition, had one wheel that crossed over the edge line. More detailed information regarding observed road departures is provided in Section 5 of this report.

4.3.9. Crashes by Brake System

Table 29 summarizes results for percent of crashes during the incursion scenario according to brake system and pavement condition. In the wet pavement study, the difference was statistically significant [X^2 = 9.879, p = 0.002], with subjects in the ABS condition crashing significantly less than subjects in the conventional brake system condition.

Table 29. Percent of subjects who crashed into the incursion vehicle as a function of brake system and pavement condition. (Value pairs marked with one or more asterisks were significantly different.)

Brake System	Dry			Wet		
	Percent Crashes	X^2	P-value	Percent Crashes	X^2	P-value
Conventional	45	1.084	0.298	100*	9.879	0.002
ABS	38			58*		

In the dry pavement study, 37 percent of 41 subjects who activated ABS during their crash avoidance maneuver, crashed into the incursion vehicle and 38 percent of 87 subjects who had ABS but did not activate it, also crashed. Also in the dry pavement study, 56 percent of 18 subjects who locked the vehicle's wheels, crashed into the incursion vehicle and 41 percent of 46 subjects who had conventional brakes but did not lock the wheels, also crashed.

In the wet pavement study, 60 percent of 35 subjects who activated ABS during their crash avoidance maneuver, crashed into the incursion vehicle. One subject had ABS but did not activate it, and also did not crash. Also in the wet pavement study, 100 percent of 16 subjects who locked the vehicle's wheels crashed into the incursion vehicle and the single subject who had conventional brakes but did not lock the wheels, also crashed.

4.4. ABS BRAKE PEDAL FEEDBACK

4.4.1. Scenario Entrance Speed by ABS Brake Pedal Feedback Level

Scenario entrance speed did not differ significantly by ABS brake pedal feedback level. Results for this measure as a function of ABS brake pedal feedback level are presented in Table 30.

Table 30. Scenario entrance speed by ABS brake pedal feedback level.

ABS Brake Pedal Feedback Level	Dry						Wet					
	N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Light	64	44	3	27	48	0.5460	18	34	1	32	36	0.4366
Heavy	64	44	2	40	50		18	35	2	31	37	

4.4.2. Reaction Times by ABS Brake Pedal Feedback Level

Reaction Time by ABS Brake Pedal Feedback Level. Table 30 shows results for reaction time as a function of ABS brake pedal feedback level.

Time to Throttle Release by ABS Brake Pedal Feedback Level. Values for mean time to throttle release did not show a significant effect due to ABS brake pedal feedback condition for dry pavement, but a significant difference was found for wet pavement. Mean values are summarized in Table 31.

Table 31. Reaction times by ABS brake pedal feedback level.

MEASURE	ABS Brake Pedal Feedback Level	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Reaction Time (s)	Light	64	1.13	0.30	0.23	1.94	0.3510	18	1.17	0.21	0.93	1.80	0.0054
	Heavy	62	1.18	0.31	0	1.93		17	0.91	0.29	0.20	1.32	
Time (s) to Throttle Release	Light	64	1.16	0.28	0.55	1.94	0.3892	18	1.18	0.21	0.93	1.80	0.0442
	Heavy	62	1.21	0.28	0.80	1.93		17	0.98	0.33	0.20	1.60	

4.4.3. Steering Behavior by ABS Brake Pedal Feedback Level

Results for steering behavior as a function of ABS brake pedal feedback level are summarized below.

Time to Initial Steering Input by ABS Brake Pedal Feedback Level. Results for the mean time to the first steering input did not show significant differences for ABS condition subjects as a function of ABS brake pedal feedback level for either pavement condition (see Table 32).

Initial Steering Input Magnitude by ABS Brake Pedal Feedback Level. Mean initial steering input magnitude results are summarized in Table 32.

Avoidance Steering Input Magnitude by ABS Brake Pedal Feedback Level. Results for mean avoidance steering input magnitude are presented in Table 32.

Avoidance Steering Input Range by ABS Brake Pedal Feedback Level. Mean values for avoidance steering input range did not differ significantly as a function of ABS brake pedal feedback level for dry pavement ($p = 0.7835$) or wet pavement ($p = 0.9489$).

Time to Maximum Steering Input by ABS Brake Pedal Feedback Level. Results for mean time to maximum steering input as a function of ABS brake pedal feedback level are listed in Table 32.

Maximum Steering Input Magnitude by ABS Brake Pedal Feedback Level. Maximum steering input magnitudes did not differ significantly by ABS brake pedal feedback level for dry pavement ($p = 0.6273$) or wet pavement ($p = 0.9652$).

Maximum Steering Input Rate by ABS Brake Pedal Feedback Level. Values for mean maximum steering rate observed during the avoidance maneuver for both light and heavy ABS brake pedal feedback conditions was 246 degrees per second. The mean maximum steering rate did not differ significantly as a function of ABS brake pedal feedback level for wet pavement ($p = 0.2289$) due to the large standard deviations.

First Lane Recovery Steering Input Range by ABS Brake Pedal Feedback Level. Values for mean first lane recovery steering input range did not differ significantly for either pavement condition. These values are summarized in Table 32.

Total Number of Steering Inputs Made During the Avoidance Maneuver by ABS Brake Pedal Feedback Level. As with lane recovery steering input range, the total number of steering inputs made during the crash avoidance maneuver was nearly identical for both ABS brake pedal feedback levels on wet pavement, but varied slightly, although not significantly, for dry pavement conditions. These results are presented in Table 32.

Table 32. Steering behavior measures by ABS brake pedal feedback level.

MEASURE	ABS Brake Pedal Feedback Level	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Steering Input	Light	62	1.60	0.56	0.23	3.10	0.3941	18	1.45	0.37	1.12	2.71	0.3625
	Heavy	59	1.71	0.68	0	4.26		18	1.32	0.46	0.69	2.45	
Initial Steering Input Magnitude (degrees)	Light	62	27	25	6	113	0.3620	18	28	25	7	95	0.3002
	Heavy	57	32	30	6	129		18	37	27	8	90	
Avoidance Steering Input Magnitudes (degrees)	Light	62	49	35	2	136	0.9473	18	58	52	7	209	0.6898
	Heavy	58	49	41	7	197		18	64	40	10	169	
Avoidance Steering Input Range (degrees)	Light	61	53	38	7	147	0.7835	18	64	73	7	302	0.9489
	Heavy	55	55	46	7	215		18	62	53	12	210	
Time (s) to Maximum Steering Input	Light	62	2.67	0.95	1.17	5.99	0.4953	18	2.47	0.62	1.67	4.33	0.4163
	Heavy	60	2.80	0.92	1.45	6.72		18	2.31	0.48	1.04	2.86	
Maximum Steering Input Magnitude (degrees)	Light	62	54	37	8	137	0.6273	18	62	52	7	209	0.9652
	Heavy	59	52	42	8	221		18	63	34	10	122	
Maximum Steering Input Rate (degrees/s)	Light	62	246	176	30	710	0.9949	18	362	322	35	1335	0.2289
	Heavy	60	246	204	32	1159		18	264	170	41	571	
First Lane Recovery Steering Input Range (degrees)	Light	58	95	65	7	227	0.4108	18	100	78	7	302	0.9958
	Heavy	49	106	78	9	418		18	100	58	12	176	
Total Number of Steering Inputs During the Avoidance Maneuver	Light	62	4.0	1.6	1	7	0.1595	18	4.6	1.3	2	7	0.7928
	Heavy	57	3.6	1.4	1	7		18	4.7	1.2	3	8	

4.4.4. Braking Behavior by ABS Brake Pedal Feedback Level

Descriptive Statistical results for measures of braking behavior as a function of ABS brake pedal feedback level are presented in Table 33.

Time to Initial Brake Input (Brake Application Reaction Time) by ABS Brake Pedal Feedback Level. Results for time to initial brake input as a function of ABS brake pedal feedback level are listed in Table 33.

Throttle to Brake Application Transition Time by ABS Brake Pedal Feedback Level. Results for mean throttle to brake transition time as a function of ABS brake pedal feedback level are listed in Table 33.

Throttle to Maximum-Brake Application Transition Time by ABS Brake Pedal Feedback Level. Results for mean throttle to maximum brake application transition time as a function of ABS brake pedal feedback level are listed in Table 33.

Time to Maximum Brake Input by ABS Brake Pedal Feedback Level. Results for mean time to maximum brake input did not show a significant difference due to ABS brake pedal feedback level for either pavement condition. These results are summarized in Table 33.

Table 33. Braking behavior measures by ABS brake pedal feedback level.

MEASURE	ABS Brake Pedal Feedback Level	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time to Initial Brake Input (s)	Light	63	1.47	0.31	0.61	2.29	0.4926	18	1.46	0.35	1.11	2.41	0.1622
	Heavy	64	1.51	0.30	1.10	2.20		18	1.31	0.29	0.88	2.03	
Throttle to Brake Application Transition Time (s)	Light	63	0.31	0.20	-0.13	0.78	0.8851	18	0.28	0.27	0.06	1.19	0.7748
	Heavy	62	0.30	0.16	-0.14	0.79		17	0.32	0.31	0.01	1.27	
Throttle to Maximum Brake Application Transition Time (s)	Light	63	1.14	0.45	0.30	2.45	0.9893	18	1.00	0.48	0.34	2.15	0.3068
	Heavy	64	1.14	0.68	0.28	4.04		17	1.17	0.52	0.29	2.03	
Time (s) to Maximum Brake Input	Light	63	2.30	0.42	1.35	3.51	0.5595	18	2.17	0.45	1.54	3.17	0.8828
	Heavy	64	2.26	0.43	1.30	3.41		18	2.15	0.51	1.34	3.11	
Maximum Brake Pedal Force (lbs)	Light	63	65	30	9	168	0.9984	18	81	50	13	240	0.2674
	Heavy	64	65	31	3	188		18	63	39	12	146	
Mean Brake Pedal Application Duration (s)	Light	63	2.18	1.15	0.05	5.39	0.8072	18	2.82	1.47	0.49	6.09	0.0059
	Heavy	64	2.21	1.12	0.01	5.15		18	1.34	1.49	0.11	5.82	

Maximum Brake Pedal Force by ABS Brake Pedal Feedback Level. Maximum brake pedal force values did not differ significantly as a function of ABS brake pedal feedback level for either pavement condition. These results are presented in Table 33.

Brake Pedal Application Duration by ABS Brake Pedal Feedback Level. Mean brake pedal application duration did not differ significantly as a function of ABS brake pedal feedback level for the dry pavement study ($p = 0.8072$) but did produce a significant result for wet pavement ($p = 0.0059$). Descriptive statistics for this measure are provided in Table 33. Results for mean brake pedal application duration by ABS brake pedal feedback level and pavement condition results are illustrated in Figures 35 and 36. These figures permit the comparison of mean brake pedal application duration by ABS brake pedal feedback level as a function of pavement condition. These data should be viewed with caution since the nature of the testing and data extraction methods available introduced complications in the determination of values for this metric.

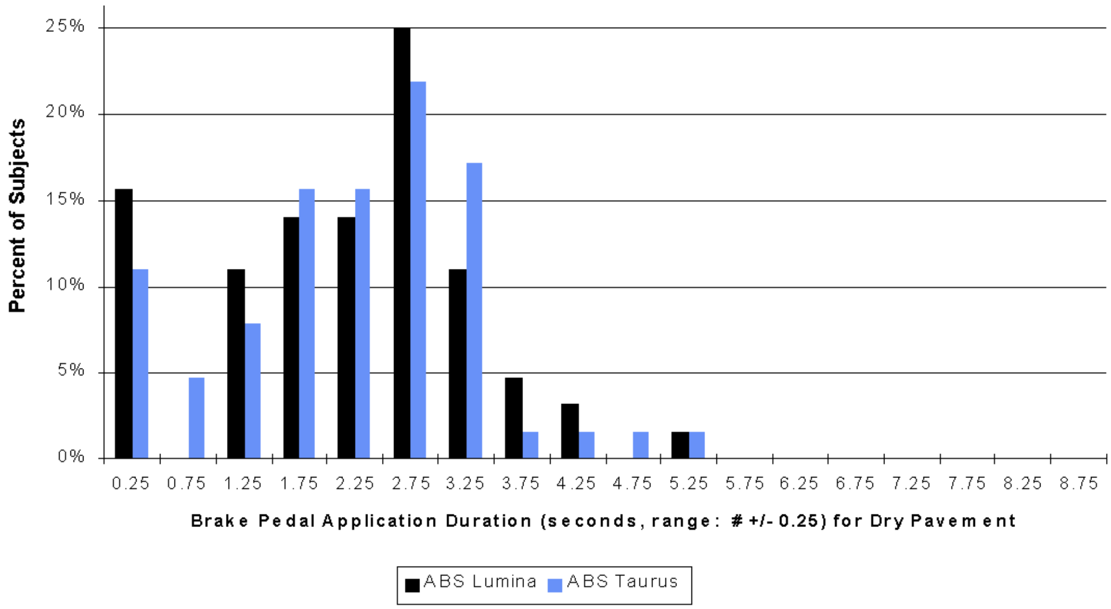

Figure 35. Frequency distribution graph for brake pedal application duration for ABS by vehicle for dry pavement. (Lumina = light feedback, Taurus = heavy feedback)

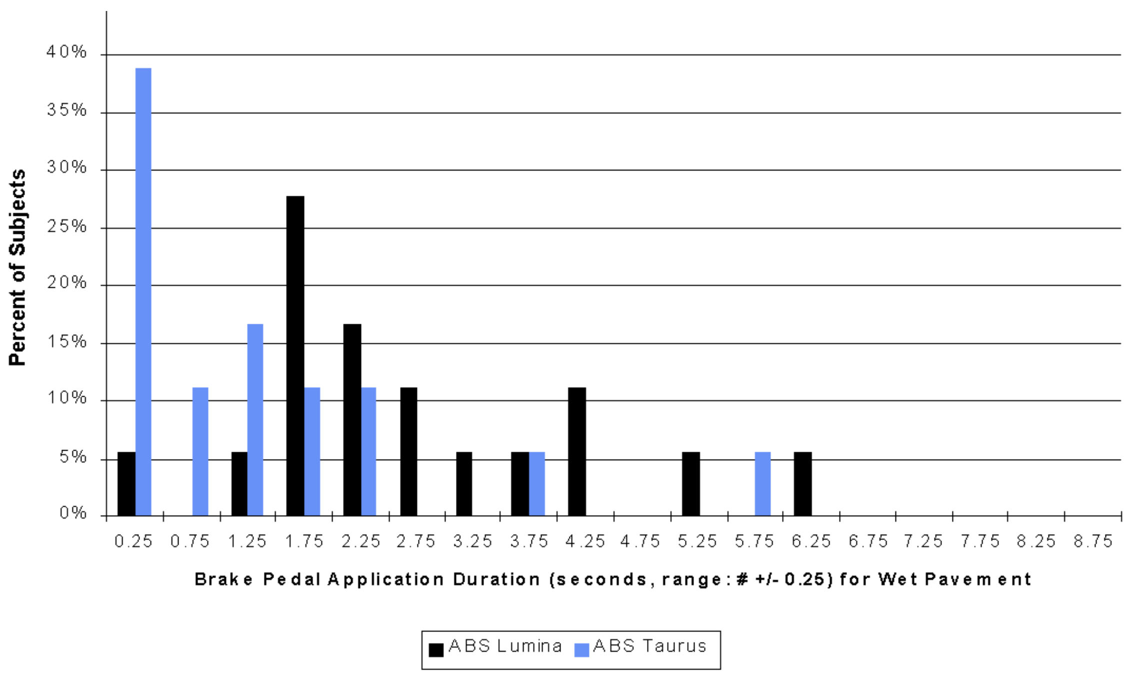

Figure 36. Frequency distribution graph for brake pedal application duration for ABS by vehicle for wet pavement.

Wheel Lockup and ABS Activations by ABS Brake Pedal Feedback Level. Results for percent wheel lockups and percent ABS activations by ABS brake pedal feedback level are provided in Table 34. In the dry pavement study, there was a significant difference in the percentage of ABS activations between the light and heavy ABS brake pedal feedback levels. Results of the wet pavement study showed high percentages of ABS activations and wheel lockup for both vehicles and feedback levels with none being significantly different from another.

Table 34. ABS activations and conventional wheel lockup percentages by ABS brake pedal feedback levels, brake system, and vehicle.

Brake System	ABS Brake Pedal Feedback Level or Vehicle	Dry			Wet		
		Mean	X^2	P-value	Mean	X^2	P-value
ABS - Percent Activation	Overall	32	NA	NA	97	NA	NA
	Light (Lumina)	47	12.954	0.001	100	1.029	0.310
	Heavy (Taurus)	17			94		

Missed Brake Pedal Applications by ABS Brake Pedal Feedback Level. Table 35 provides results for percentages of missed brake pedal application attempts during the crash avoidance maneuver as a function of ABS brake pedal feedback level.

Table 35. Percentages of brake pedal misses and braking application techniques by brake system.

Brake System	ABS Brake Pedal Feedback Level	Percent of Subjects Who Missed Brake Pedal One Time			Percent of Subjects Who Missed Brake Pedal Two Times			Percent of Subjects Who Used a Non-Standard Brake Application Technique		
		Dry	Wet	Both	Dry	Wet	Both	Dry	Wet	Both
Conventional	**NA**	32	0	25	0	0	0	7	0	5
ABS	**Light**	25	6	21	10	0	7	6	6	6
	Heavy	25	21	24	2	0	1	9	0	7

4.4.5. Deceleration by ABS Brake Pedal Feedback Level

An analysis was conducted to determine the average maximum deceleration achieved by subjects as a function of ABS brake pedal feedback level. Overall (across pavement conditions), the mean maximum deceleration was 0.70 g (SD 0.30, max 1.15, min 0.01) for subjects in the light ABS brake pedal feedback condition and 0.63 g (SD 0.18, max 0.97, min 0.004) for those in the heavy feedback condition. These values were not significantly different (p = 0.0784). Results for this measure by pavement condition are listed in Table 36.

Table 36. Accelerations by ABS brake pedal feedback level.

MEASURE	ABS Brake Pedal Feedback Level	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Maximum Deceleration (g)	Light	64	0.77	0.30	0.01	1.15	0.0646	18	0.47	0.11	0.17	0.67	0.4199
	Heavy	64	0.69	0.15	0.08	0.97		18	0.43	0.12	0.00 4	0.55	
Maximum Lateral Acceleration (g)	Light	64	0.26	0.18	0.03	0.61	0.7126	18	0.27	0.12	0.08	0.51	0.2132
	Heavy	64	0.25	0.19	0.03	0.73		18	0.22	0.14	0.01	0.39	

4.4.6. Lateral Acceleration by ABS Brake Pedal Feedback Level

Values for mean maximum lateral acceleration did not differ significantly as a function of ABS brake pedal feedback level for either pavement condition. These results are presented in Table 36.

4.4.7. Road Departures by ABS Brake Pedal Feedback Level

Full Road Departures. As stated earlier, two instances of the test vehicle fully departing the roadway were observed in the dry pavement study. Both of these road departures involved the ABS-equipped vehicle with heavy brake pedal feedback.

Partial Road Departures. Two partial road departures were observed on dry pavement, one with ABS and one with conventional brakes. Each of these cases occurred in the same vehicle, the heavy ABS brake pedal feedback vehicle (Taurus). In the wet pavement study, only one road departure occurred, a partial road departure experienced by a subject also driving the Taurus configured with conventional brakes. Additional information regarding road departures is provided in Section 5.

4.4.8. Crashes by ABS Brake Pedal Feedback Level

Table 37 shows the percentage of subjects who collided with the incursion vehicle by pavement condition and ABS brake pedal feedback level. Crash results are also listed for only subjects who activated ABS. In the dry pavement study, there was a significant difference in the percentage of crashes between the light and heavy ABS brake pedal feedback vehicles of those subjects who activated ABS* [$X^2 = 4.742$, $p = 0.0029$].

An examination of percent crashes on wet pavement for subjects in the heavy ABS brake pedal feedback condition versus conventional brake system subjects also revealed a significant difference [$X^2 = 13.222$, $p = 0.001$].

Table 37. Percent Crashes by ABS brake pedal feedback levels, brake system, and whether ABS was activated.

MEASURE	ABS Brake Pedal Feedback Level (or Vehicle)	Dry	Wet
Percent Crashes Overall	Light (Lumina)	33	72
	Heavy (Taurus)	42	44
Percent Crashes for Those Who Activated ABS	Light (Lumina)	27 *	72
	Heavy (Taurus)	64 *	47

4.5. VEHICLE

In order to assess whether the use of two different test vehicles to create the two different ABS brake pedal feedback levels had any unintended effects on the test results, an analysis of "vehicle" as an independent variable was performed. If no effects of "vehicle" were found, then it could be assumed that comparisons made by ABS brake pedal feedback level would not be confounded by vehicle effects.

Some significant effects were observed in the results. The Lumina showed higher mean deceleration values on dry pavement than did the Taurus. The vehicles also appeared to show different trends in the magnitudes and ranges of steering inputs for the conventional brake system condition and 'overall', but not for ABS on wet pavement. Mean time to throttle release was shorter for the Taurus when compared to the Lumina for the ABS condition on wet pavement. In addition, the Taurus had shorter mean time to maximum brake application values than the Lumina for conditions of dry pavement. Brake pedal application duration was shorter for the Taurus for all three of the ABS, conventional brake system, and 'overall' analysis categories. For dry pavement, the Taurus was associated with significantly fewer cases of wheel lockup with conventional brakes and ABS activations than the Lumina.

For ease of comparison, these data are listed in tabular format in Tables 38 through 43. Some data presented in these tables are repeated from earlier sections.

Table 38. Comparisons for scenario entrance speed and reaction times by brake system, vehicle, and pavement condition. (Non-significant results are denoted by shaded p-values.)

MEASURE	Brake System	Vehicle	Dry		Wet	
			Mean	P-Value	Mean	P-Value
Mean Scenario Entrance Speed (mph)	ABS	Lumina	44	0.5460	34	0.4366
		Taurus	44		35	
	Conventional	Lumina	44	0.9351	32	0.1153
		Taurus	44		34	
	Overall	Lumina	44	0.4641	34	0.0704
		Taurus	44		35	
Mean Reaction Time (s)	ABS	Lumina	1.13	0.3510	1.17	0.0054
		Taurus	1.18		0.9	
	Conventional	Lumina	1.16	0.4425	1.21	0.8643
		Taurus	1.23		1.18	
	Overall	Lumina	1.14	0.6942	1.18	0.9329
		Taurus	1.20		1.00	
Mean Time to Throttle Release (s)	ABS	Lumina	1.16	0.3892	1.18	0.0442
		Taurus	1.21		0.98	
	Conventional	Lumina	1.15	0.2154	1.21	0.8712
		Taurus	1.25		1.19	
	Overall	Lumina	1.16	0.7901	1.19	0.7994
		Taurus	1.22		1.04	
Mean Time to Initial Steering Input (s)	ABS	Lumina	1.60	0.3941	1.45	0.3625
		Taurus	1.71		1.32	
	Conventional	Lumina	1.72	0.1364	1.66	0.3577
		Taurus	1.56		1.47	
	Overall	Lumina	1.64	0.7525	1.51	0.1491
		Taurus	1.66		1.37	
Mean Time to Initial Brake Pedal Application (s)	ABS	Lumina	1.47	0.4926	1.46	0.1622
		Taurus	1.51		1.31	
	Conventional	Lumina	1.50	0.6973	1.57	0.4903
		Taurus	1.53		1.44	
	Overall	Lumina	1.48	0.3956	1.49	0.8641
		Taurus	1.51		1.35	

Table 39. Comparisons for steering and brake input measures by brake system, vehicle, and pavement condition. (Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System	Vehicle	Dry		Wet	
			Mean	P-Value	Mean	P-Value
Mean Avoidance Steering Input Magnitude (degrees)	ABS	Lumina	49	0.9473	58	0.6898
		Taurus	49		64	
	Conventional	Lumina	67	0.3605	154	0.0157
		Taurus	55		53	
	Overall	Lumina	55	0.5242	88	0.0141
		Taurus	51		61	
Mean Avoidance Steering Input Range (degrees)	ABS	Lumina	53	0.7835	64	0.9489
		Taurus	55		62	
	Conventional	Lumina	59	0.8326	152	0.0545
		Taurus	62		51	
	Overall	Lumina	54	0.6078	91	0.0464
		Taurus	57		59	
Mean Maximum Steering Input Magnitude (degrees)	ABS	Lumina	54	0.6273	62	0.9652
		Taurus	51		63	
	Conventional	Lumina	67	0.7664	154	0.0208
		Taurus	63		59	
	Overall	Lumina	58	0.6267	90	0.0071
		Taurus	55		62	
Mean Maximum Steering Input Rate (degrees/s)	ABS	Lumina	246	0.9949	362	0.2289
		Taurus	246		264	
	Conventional	Lumina	281	0.5972	329	0.0760
		Taurus	310		172	
	Overall	Lumina	257	0.6065	351	0.0140
		Taurus	267		236	
Mean Throttle to Brake Application Transition Time (s)	ABS	Lumina	0.31	0.8851	0.28	0.7748
		Taurus	0.30		0.32	
	Conventional	Lumina	0.35	0.1365	0.36	0.5072
		Taurus	0.28		0.26	
	Overall	Lumina	0.32	0.3207	0.31	0.6866
		Taurus	0.30		0.30	
Mean Throttle to Maximum Brake Application Transition Time (s)	ABS	Lumina	1.14	0.9893	1.00	0.3068
		Taurus	1.14		1.17	
	Conventional	Lumina	1.32	0.0983	1.73	0.1276
		Taurus	1.03		0.99	
	Overall	Lumina	1.20	0.2273	1.22	0.4001
		Taurus	1.10		1.12	
Mean Time to Maximum Brake Application (s)	ABS	Lumina	2.30	0.5595	2.17	0.8828
		Taurus	2.26		2.15	
	Conventional	Lumina	2.46	0.0338	2.88	0.0899
		Taurus	2.20		2.18	
	Overall	Lumina	2.36	0.0495	2.41	0.1609
		Taurus	2.24		2.16	

Table 40. Comparisons for brake input magnitudes by brake system, vehicle, and pavement condition (cont.). (Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System	Vehicle	Dry		Wet	
			Mean	P-Value	Mean	P-Value
Average Maximum Brake Pedal Force (pounds)	ABS	Lumina	65	0.9984	81	0.2674
		Taurus	65		63	
	Conventional	Lumina	69	0.1089	61	0.7345
		Taurus	56		57	
	Overall	Lumina	66	0.2518	74	0.2621
		Taurus	62		61	
Average Maximum Deceleration (g)	ABS	Lumina	0.77	0.0646	0.47	0.4199
		Taurus	0.69		0.43	
	Conventional	Lumina	0.78	0.0072	0.43	0.4337
		Taurus	0.62		0.46	
	Overall	Lumina	0.77	0.0026	0.45	0.1723
		Taurus	0.67		0.44	
Brake Pedal Application Duration (s)	ABS	Lumina	2.18	0.8072	2.82	0.0059
		Taurus	2.21		1.34	
	Conventional	Lumina	2.37	0.0357	5.18	0.0001
		Taurus	1.60		1.04	
	Overall	Lumina	2.24	0.1205	3.61	0.0001
		Taurus	2.01		1.25	
Wheel Lockup / ABS Activations	ABS	Lumina	47 %	0.0010	100 %	0.3100
		Taurus	17 %		94 %	
	Conventional	Lumina	44 %	0.0050	89 %	0.3310
		Taurus	13 %		100 %	
	Overall	Lumina	46 %	0.0010	96 %	0.9780
		Taurus	16 %		96 %	

Figure 37 and 38 illustrate results for brake pedal application duration by vehicle for dry and wet pavement.

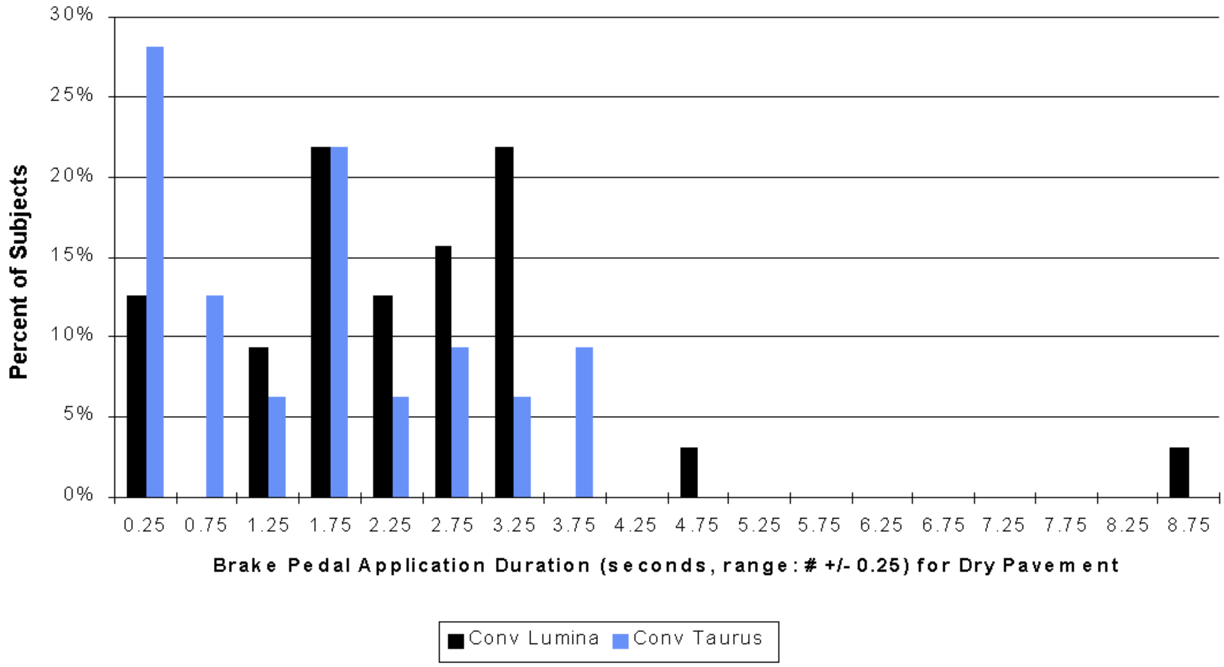

Figure 37. Frequency distribution graph for brake pedal application duration for conventional brake system by vehicle for dry pavement. (Lumina = light feedback, Taurus = heavy feedback)

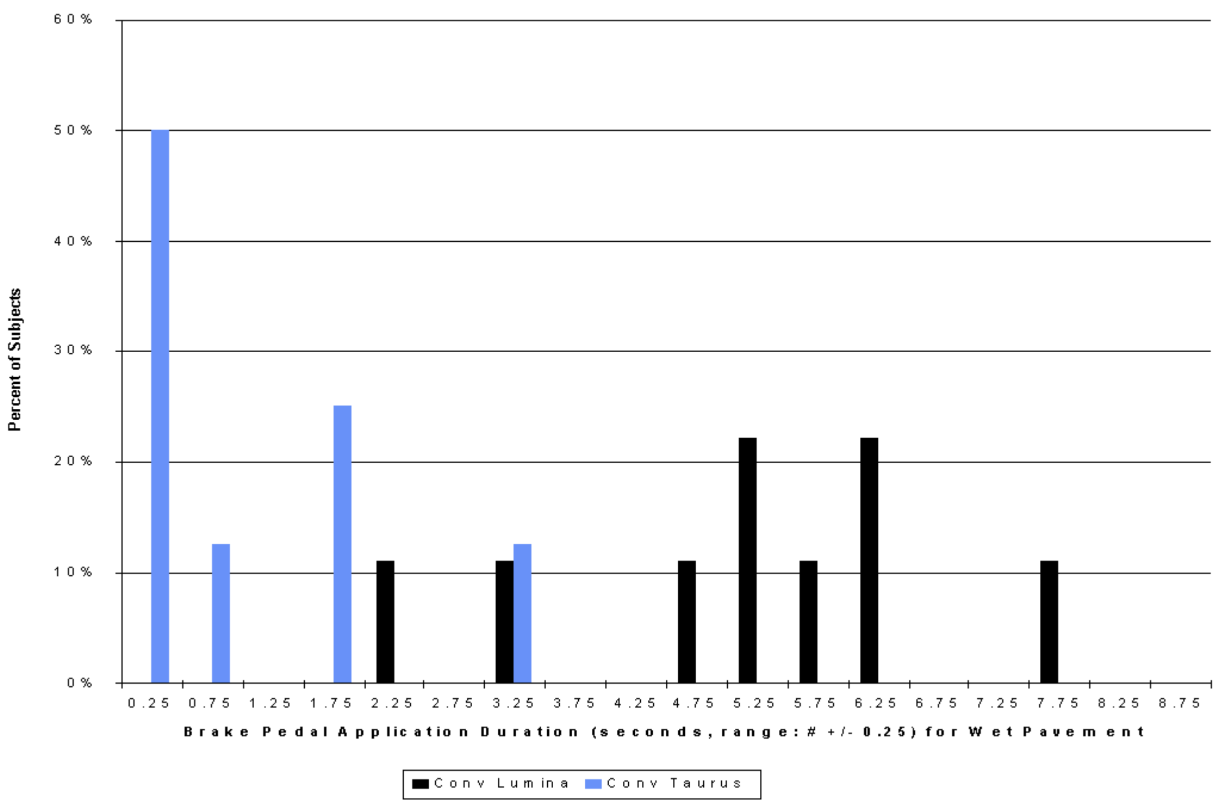

Figure 38. Frequency distribution graph for brake pedal application duration for the conventional brake system condition by vehicle for wet pavement.

Table 41. Comparisons for lane recovery, lateral acceleration, and crashes by brake system, vehicle, and pavement condition. (Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System	Vehicle	Dry		Wet	
			Mean	P-Value	Mean	P-Value
Average First Lane Recovery Steering Input Range (degrees)	ABS	Lumina	95	0.4108	100	0.9958
		Taurus	106		100	
	Conventional	Lumina	107	0.5634	128	0.3554
		Taurus	97		85	
	Overall	Lumina	99	0.8696	109	0.2087
		Taurus	102		95	
Lateral Acceleration (g)	ABS	Lumina	0.26	0.7126	0.27	0.2132
		Taurus	0.25		0.22	
	Conventional	Lumina	0.24	0.3616	0.20	0.5179
		Taurus	0.28		0.23	
	Overall	Lumina	0.25	0.7424	0.25	0.3599
		Taurus	0.26		0.22	
Crashes with Incursion Vehicle (%)	ABS	Lumina	33 %	0.2730	72 %	0.0910
		Taurus	42 %		44 %	
	Conventional	Lumina	44 %	0.8020	100 %	NA
		Taurus	47 %		100 %	
	Overall	Lumina	36 %	0.3030	81 %	0.1070
		Taurus	44 %		62 %	

Table 42. Road departures by brake system, vehicle and pavement condition.

MEASURE	Brake System	Vehicle	Dry		Wet	
			Full	Partial	Full	Partial
Road Departures	ABS	Lumina	0	0	0	0
		Taurus	2	1	0	0
	Conventional	Lumina	0	0	0	0
		Taurus	0	1	0	1
	Overall	Lumina	0	0	0	0
		Taurus	2	2	0	1

Wheel Lockup and ABS Activations by Vehicle. Results for percent wheel lockups and percent ABS activations by vehicle are provided in Table 43. In the dry pavement study, there was a significant difference in the percentage of ABS activations between the two vehicles. There was also a significant difference in the percentage of conventional wheel lockups between the vehicles in the dry pavement study. Results of the wet pavement study showed high percentages of ABS activations and wheel lockup for both vehicles and feedback levels with none being significantly different from another.

Table 43. ABS activations and conventional wheel lockup percentages by ABS brake pedal feedback levels, brake system, and vehicle.

Brake System	ABS Brake Pedal Feedback Level or Vehicle	Dry			Wet		
		Mean	X^2	P-value	Mean	X^2	P-value
Conventional – Percent Lockup	Overall	28	NA	NA	94	NA	NA
	Lumina	44	7.729	0.005	89	0.944	0.331
	Taurus	13			100		
ABS - Percent Activation	Overall	32	NA	NA	97	NA	NA
	Light (Lumina)	47	12.954	0.001	100	1.029	0.310
	Heavy (Taurus)	17			94		

Missed Brake Pedal Applications by Vehicle. Table 44 briefly presents results for missed brake pedal applications by vehicle and gender. Twelve subjects for whom video data was not successfully recorded were not included in this analysis.

Table 44. Brake pedal misses and braking application techniques by vehicle and gender.

Vehicle	Gender	Percent of Subjects Who Missed Brake Pedal One Time			Percent of Subjects Who Missed Brake Pedal Two Times			Percent of Subjects Who Used a Non-Standard Brake Application Technique		
		Dry	Wet	Both	Dry	Wet	Both	Dry	Wet	Both
Lumina	**Male**	22	8	19	0	0	0	12	0	10
	Female	34	0	25	14	0	10	2	7	3
	Overall	27	4	22	6	0	5	7	4	7
Taurus	**Male**	17	0	14	2	0	2	8	0	7
	Female	41	27	38	0	0	0	5	0	4
	Overall	27	14	24	1	0	1	7	0	6

4.5.1. Steering Behavior by Vehicle

In addition to the steering measure results listed in Table 39, a frequency distribution analysis of maximum steering input range by vehicle was also conducted to identify any differences between the amount of steering performed by subjects according to vehicle. Differences between these distributions could indicate inherent steering system differences between the vehicles that could have an impact on other steering measures. Minimal differences were found between the two vehicles based on the maximum steering input range frequency distribution graphs as shown in Figure 39.

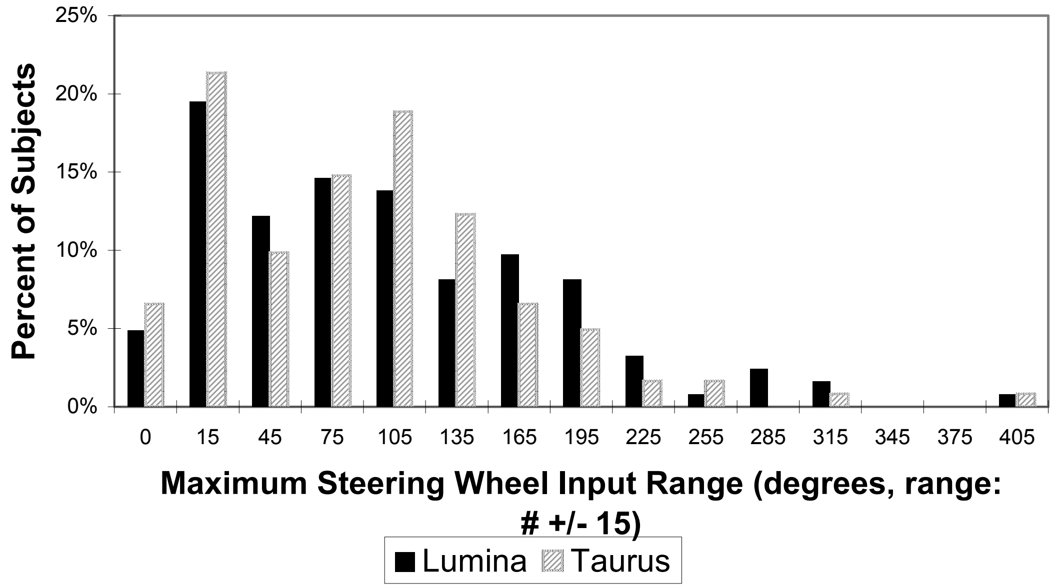

Figure 39. Maximum steering wheel input range frequency distributions by vehicle.

4.5.2. Deceleration by Vehicle

Deceleration results are provided in Table 40. Results for average maximum deceleration differed significantly ($p = 0.0026$) by vehicle for dry pavement. On average, subjects achieved higher rates of deceleration on dry pavement in the Lumina than in the Taurus. Twenty-eight subjects achieved maximum decelerations of greater than or equal to 1.0 g in the Lumina. The highest maximum deceleration rate of any subject driving the Lumina was 1.15 g. Examination of data for individual subjects showed that these values were correct and were not a product of "spikes" in the data. Accelerometer calibrations were confirmed to ensure that sensors were reading accurately during testing.

4.6. ABS INSTRUCTION

During the pre-briefing phase of the test procedure, some subjects were shown an educational video containing vehicle safety information and a description of the function and operation of ABS. Details regarding the content of this instruction are provided in Section 3.3.4. In the dry pavement study, 64 of the 128 ABS subjects received the ABS instruction. In the wet pavement study, 18 of the 36 ABS subjects received the ABS instruction. Comparisons between the ABS subjects with instruction versus no instruction follow. Since ABS has previously been compared to conventional brakes and numbers were given, the conventional brake system condition will not be shown unless a significant difference was found between ABS instruction and the conventional brake condition that was not found between overall ABS and conventional brakes.

4.6.1. Scenario Entrance Speed by ABS Instruction

Scenario entrance speed did not differ significantly by ABS instruction as can be seen from the mean and standard deviation values. Results for entrance speed as a function of ABS instruction are listed in Table 45.

Table 45. Scenario Entrance Speeds by ABS instruction.

ABS Instruction	Dry					Wet				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Instruction	64	44	2	40	47	18	34	2	31	36
No instruction	64	44	3	27	50	18	35	1	34	37

4.6.2. Reaction Times by ABS Instruction

Reaction Time by ABS Instruction. Mean reaction time did not differ significantly as a function of whether or not subjects received ABS instruction for either pavement condition. Descriptive results are presented in Table 46.

Time to Throttle Release by ABS Instruction. Mean time to throttle release did not differ significantly as a function of whether or not subjects received ABS instruction. Descriptive results are presented in Table 46.

Table 46. Reaction times by ABS instruction.

MEASURE	ABS Instruction	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Reaction Time (s)	Instruction	63	1.12	0.33	0	1.94	0.1603	17	1.05	0.22	0.62	1.40	0.9295
	No instruction	63	1.19	0.28	0.80	1.93		18	1.04	0.33	0.20	1.80	
Time (s) to Throttle Release	Instruction	63	1.17	0.28	0.55	1.94	0.5741	17	1.11	0.23	0.62	1.60	0.5348
	No instruction	63	1.20	0.29	0.80	1.93		18	1.05	0.33	0.20	1.80	

4.6.3. Steering Behavior by ABS Instruction

Results for steering behavior measures as a function of ABS instruction are listed in Table 47.

Time to Initial Steering Input by ABS Instruction. Mean time to initial steering input did not differ significantly as a function of whether or not subjects received ABS instruction.

Initial Steering Input Magnitude by ABS Instruction. There were no significant differences found for initial steering input magnitude by ABS instruction for dry or wet pavement.

Avoidance Steering Input Magnitude by ABS Instruction. In the dry pavement study, the effect of ABS instruction on the mean magnitude of the avoidance steering input was nearly statistically significant ($p = 0.0792$). For wet pavement, the effect of ABS instruction on the mean magnitude of the avoidance steering input was not significant.

Avoidance Steering Input Range by ABS Instruction. Subjects' average avoidance steering input range did not differ significantly as a function of ABS instruction for dry or wet pavement.

Time to Maximum Steering Input by ABS Instruction. Mean time to maximum steering input did not differ significantly as a function of ABS instruction for dry ($p = 0.3455$) or wet ($p = 0.8345$) pavement.

Table 47. Steering behavior by ABS instruction.

MEASURE	ABS Instruction	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Steering Input	Instruction	61	1.69	0.75	0	4.26	0.4133	18	1.33	0.31	0.69	1.89	0.4335
	No instruction	60	1.62	0.47	0.92	2.97		18	1.44	0.51	0.73	2.71	
Initial Steering Input Magnitude (degrees)	Instruction	59	26	26	6	129	0.1573	18	34	28	9	95	0.7721
	No instruction	60	32	29	7	113		18	31	25	7	86	
Avoidance Steering Input Magnitude (degrees)	Instruction	60	43	34	2	129	0.0792	18	71	56	10	209	0.2090
	No instruction	60	55	41	7	197		18	52	30	7	122	
Avoidance Steering Input Range (degrees)	Instruction	57	51	41	7	215	0.6916	18	74	76	7	302	0.3296
	No instruction	59	55	43	7	175		18	53	48	7	210	
Time (s) to Maximum Steering Input	Instruction	62	2.79	1.01	1.17	6.72	0.3455	18	2.41	0.68	1.04	4.33	0.8345
	No instruction	60	2.68	0.84	1.18	5.99		18	2.37	0.41	1.37	2.96	
Maximum Steering Input Magnitude (degrees)	Instruction	61	46	33	8	129	0.0734	18	71	53	10	209	0.2318
	No instruction	60	60	44	8	221		18	54	30	7	122	
Maximum Steering Input Rate (degrees/s)	Instruction	61	216	170	30	685	0.0773	18	363	336	41	133 5	0.2203
	No instruction	61	276	204	30	1159		18	263	138	35	571	
First Lane Recovery Steering Input Range (degrees)	Instruction	52	89	61	7	241	0.1595	18	116	80	12	302	0.1249
	No instruction	55	110	79	9	418		18	83	48	7	176	
Total Number of Steering Inputs During Avoidance Maneuver	Instruction	59	3.7	1.5	1	7	0.6707	18	4.8	1.1	3	7	0.2972
	No instruction	60	3.9	1.6	1	7		18	4.4	1.4	2	8	

Maximum Steering Input Magnitude by ABS Instruction. Subjects' average maximum steering input magnitude did not show a significant effect of ABS instruction for dry or wet pavement.

Maximum Steering Input Rate by ABS Instruction. Results for the mean maximum steering rate did not show a statistically significant effect due to ABS instruction for dry or wet pavement.

First Lane Recovery Steering Input Range by ABS Instruction. The average first lane recovery input range did not differ significantly as a function of ABS instruction for dry or wet pavement.

Total Number of Steering Inputs Made During the Avoidance Maneuver by ABS Instruction. There was no significant difference found in the average total number of steering inputs made during the avoidance maneuver for dry ($p = 0.6707$) or wet pavement ($p = 0.2972$).

4.6.4. Braking Behavior by ABS Instruction

Results for braking behavior as a function of ABS instruction for subjects in the ABS condition in the dry pavement study are listed in Table 48.

Time to Initial Brake Input (Brake Application Reaction Time) by ABS Instruction. Results for time to initial brake input as a function of ABS instruction condition are listed in Table 48.

Throttle to Brake Application Transition Time by ABS Instruction. Results for mean throttle to brake transition time as a function of ABS instruction condition are listed in Table 48.

Throttle to Maximum-Brake Application Transition Time by ABS Instruction. Results for mean throttle to maximum brake application transition time as a function of ABS instruction condition are listed in Table 48.

Time to Maximum Brake Input by ABS Instruction. Results for mean time to maximum brake input did not show a significant difference due to ABS instruction for either pavement condition. These results are summarized in Table 48.

Maximum Brake Pedal Force by ABS Instruction. Maximum brake pedal force values did not differ significantly as a function of ABS instruction. Results for this measure are provided in Table 48.

Brake Pedal Application Duration by ABS Instruction. In the dry pavement study, the mean brake application duration length was significantly longer (p = 0.0082) for subjects receiving ABS instruction than for the ABS subjects who did not receive instruction. This effect was not seen for wet pavement. Results for this measure are summarized in Table 48. As stated previously, this data should be viewed with caution since the nature of the testing and data extraction methods available introduced complications in the determination of values for this metric.

Table 48. Braking behavior by ABS instruction (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	ABS Instruction	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Brake Input	Instruction	64	1.45	0.32	0.61	2.20	0.1099	18	1.30	0.20	0.88	1.68	0.1382
	No instruction	63	1.53	0.28	1.10	2.29		18	1.46	0.41	0.95	2.41	
Throttle to Brake Application Transition Time (s)	Instruction	63	0.28	0.16	-0.14	0.74	0.0797	17	0.18	0.08	0.05	0.35	0.0185
	No instruction	62	0.33	0.19	-0.08	0.79		18	0.41	0.36	0.01	1.27	
Throttle to Maximum-Brake Application Transition Time (s)	Instruction	63	1.13	0.46	0.29	2.45	0.4877	17	0.96	0.43	0.29	1.97	0.1683
	No instruction	62	1.07	0.49	0.28	2.27		18	1.20	0.54	0.48	2.15	
Time (s) to Maximum Brake Input	Instruction	64	2.30	0.44	1.30	3.37	0.6517	18	2.07	0.38	1.54	2.98	0.2467
	No instruction	63	2.27	0.41	1.35	3.51		18	2.25	0.55	1.34	3.17	
Mean Maximum Brake Pedal Force (lbs)	Instruction	64	68	28	15	188	0.3575	18	75	51	21	240	0.7074
	No instruction	63	62	32	3	170		18	69	40	12	146	
Brake Pedal Application Duration (s)	Instruction	64	2.46	1.03	0.08	5.39	0.0082	18	2.09	1.75	0.15	6.09	0.9584
	No instruction	63	1.93	1.17	0.01	5.15		18	2.06	1.57	0.11	5.46	

Wheel Lockup and ABS Activations by ABS Instruction. Tables 49 and 50 provide data for ABS activations and related crash rates as a function of ABS instruction and provide corresponding conventional brake system data for comparison.

Table 49. Percentage of ABS activations by ABS instruction and conventional brake system wheel lockup cases on dry pavement.

Brake System	ABS Instruction	% Activated ABS or Locked Wheels	% Crashed	% **Did Not** Activate ABS or Lock Wheels	% Crashed
Conventional	NA	28	56	72	41
ABS	Instruction	31	35	69	41
	No Instruction	33	38	67	35

Table 50. Percentage of ABS activations by ABS instruction and conventional brake system wheel lockups on wet pavement.

Brake System	ABS Instruction	% Activated ABS or Locked Wheels	% Crashed	% **Did Not** Activate ABS or Lock Wheels	% Crashed
Conventional	NA	94	100	6	100
ABS	Instruction	100	67	0	NA
	No Instruction	94	53	6	0

Missed Brake Pedal Applications by ABS Instruction. On dry pavement, 13 of 60 subjects in the ABS condition who did receive ABS instruction and 17 of 60 subjects who did not receive ABS instruction missed the brake pedal once during the crash avoidance maneuver. On wet pavement, 1 of 16 subjects in the ABS condition who did receive instruction and 3 of 16 subjects who did not receive ABS instruction missed the brake pedal once during the crash avoidance maneuver. Data describing rates of missed brake pedal applications and non-standard brake pedal applications (e.g., left foot braking, two-footed braking) during the crash avoidance maneuver are provided as percentages in Table 51.

Table 51. Percentage of missed and non-standard brake pedal application techniques by ABS instruction and pavement condition.

Brake System	ABS Instruction	Missed Brake Pedal Once			Missed Brake Pedal Twice			Non-Standard Brake Pedal Application		
		Dry	Wet	Both	Dry	Wet	Both	Dry	Wet	Both
ABS	Instruction	22	6	18	5	0	4	12	0	9
	No Instruction	28	19	26	7	0	5	3	6	4

4.6.5. Deceleration by ABS Instruction

An analysis was conducted to determine the average maximum deceleration achieved by subjects as a function of whether or not they received ABS instruction. Overall, the mean maximum deceleration was 0.69 g (SD 0.23, max 1.13, min 0.01) for subjects in the ABS condition who received instruction and 0.65 g (SD 0.26, max 1.15, min 0.004) for those who did not receive instruction.

These data were also examined by pavement condition. In the dry pavement study, the mean maximum deceleration for subjects in the ABS condition who received instruction was 0.75 g (SD 0.22, max 1.13, min 0.01) and 0.71 g (SD 0.26, max 1.15, min 0.08) for subjects who did not receive instruction. In the wet pavement study, the mean maximum deceleration for subjects in the ABS condition who received instruction was 0.46 g (SD 0.06, max 0.56, min 0.29) and 0.44 g (SD 0.15, max 0.67, min 0.004) for those who did not receive instruction.

4.6.6. Road Departures by ABS Instruction

Full Road Departures by ABS Instruction. As stated earlier, two subjects in the ABS condition departed the roadway fully in the dry pavement study. Both of these road departures involved subjects who did not receive instruction.

Partial Road Departures by ABS Instruction. In addition, two partial road departures were observed, one with ABS and one conventional. The one with ABS was also not given ABS instruction. As stated previously, only one road departure occurred in the wet pavement study, a partial road departure experienced by a subject driving the Taurus configured with conventional brakes.

4.6.7. Crashes by ABS Instruction

Thirty-nine percent of the 64 subjects in the ABS instruction condition collided with the incursion vehicle on dry pavement. For those not receiving instruction, 36 percent of those 64 subjects crashed on dry pavement. This difference was not statistically significant, as can be seen by the p-values listed in Table 52.

In the wet pavement study, subjects in the ABS condition crashed less than those with conventional brakes regardless of whether or not those in the ABS condition received instruction. Subjects in the ABS condition in the wet pavement study who did not receive instruction crashed at a rate of 50 percent that was significantly less than subjects with conventional brakes (X^2 = 11.442, p = 0.001). Sixty-seven percent of subjects in the ABS condition who received instruction only (no braking practice) crashed. This result was also significantly less than the percent of crashes for subjects with conventional brakes (X^2 = 6.839, p = 0.0040). However, subjects in the ABS condition who received ABS instruction did not crash significantly less than those in the ABS condition who did not receive instruction (p=?).

Table 52. Percent Crashes by ABS instruction.

Brake System	ABS Instruction	Dry			Wet		
		Mean	X^2	P-value	Mean	X^2	P-value
ABS	No Instruction	36	0.1333	0.7150	50	1.029	0.3100
	Instruction	39			67		

4.7. BRAKING PRACTICE

Braking practice was provided to half of the subjects (64/128 ABS, 32/64 conventional) in the dry pavement study as outlined in section 3.3.5.

4.7.1. Scenario Entrance Speed by Braking Practice

Scenario entrance speed did not differ significantly by braking practice. In the dry pavement study, the mean scenario entrance speed for the braking practice condition for subjects with ABS was 44 mph (SD 0, max 50, min 41) and for the subjects in the ABS condition without braking practice was 43 mph (SD 1, max 49, min 27). The mean scenario entrance speed for the braking practice condition for subjects with conventional brakes was 44 mph (SD 2, max 46, min 39) and for the subjects in the conventional brake condition without braking practice was 44 mph (SD 1, max 46, min 40).

4.7.2. Reaction Times by Braking Practice

Reaction Time by Braking Practice. Reaction time did not reveal a significant difference due to braking practice. Results are summarized in Table 53.

Time to Throttle Release by Braking Practice. There were no significant differences for mean time to throttle release as a function of braking practice. Results are summarized in Table 53.

Table 53. Reaction times by braking practice for dry pavement.

MEASURE	Brake System	Braking Practice	N	Mean	SD	Min	Max
Reaction Time (s)	ABS	Practice	64	1.14	0.32	0.23	1.94
		No Practice	62	1.17	0.30	0	1.89
	Conventional	Practice	31	1.16	0.30	0.66	1.97
		No Practice	32	1.22	0.30	0.84	2.14
Time (s) to Throttle Release	ABS	Practice	64	1.17	0.30	0.55	1.94
		No Practice	62	1.20	0.26	0.73	1.89
	Conventional	Practice	30	1.15	0.30	0.66	2.01
		No Practice	32	1.25	0.30	0.84	2.14

4.7.3. Steering Behavior by Braking Practice

Results for steering behavior as a function of braking practice are listed in Table 54.

Table 54. Steering behavior by braking practice for dry pavement (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System	Braking Practice	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Steering Input	ABS	Practice	63	1.65	0.70	0.23	4.26	0.9463
		No Practice	58	1.66	0.54	0	3.03	
	Conventional	Practice	30	1.63	0.48	1.01	2.98	0.8761
		No Practice	30	1.65	0.47	1.02	2.76	
Initial Steering Input Magnitude (degrees)	ABS	Practice	62	32	32	7	129	0.4008
		No Practice	57	26	22	6	92	
	Conventional	Practice	30	30	53	6	276	0.7515
		No Practice	30	26	33	6	179	
Avoidance Steering Input Magnitude (degrees)	ABS	Practice	62	55	44	7	197	0.1038
		No Practice	58	43	30	2	108	
	Conventional	Practice	30	62	57	6	271	0.9101
		No Practice	30	59	46	6	179	
Avoidance Steering Input Range (degrees)	ABS	Practice	62	58	48	7	215	0.1606
		No Practice	54	48	32	7	141	
	Conventional	Practice	30	63	55	7	276	0.6703
		No Practice	30	57	53	7	187	
Time (s) to Maximum Steering Input	ABS	Practice	64	2.69	0.94	1.19	6.72	0.6441
		No Practice	58	2.78	0.93	1.17	5.99	
	Conventional	Practice	30	2.65	0.66	1.55	4.12	0.4949
		No Practice	30	2.75	0.66	1.47	4.97	
Maximum Steering Input Magnitude (degrees)	ABS	Practice	63	58	44	8	221	0.1699
		No Practice	58	48	33	8	137	
	Conventional	Practice	30	69	62	7	271	0.5880
		No Practice	30	61	46	6	178	
Maximum Steering Input Rate (degrees/s)	ABS	Practice	63	278	216	30	1159	0.0507
		No Practice	59	211	150	30	670	
	Conventional	Practice	30	330	235	39	869	0.2507
		No Practice	30	262	196	30	982	
First Lane Recovery Steering Input Range (degrees)	ABS	Practice	55	109	81	7	418	0.1268
		No Practice	52	90	58	9	227	
	Conventional	Practice	30	99	67	5	246	0.6562
		No Practice	29	104	72	11	284	
Total Number of Steering Inputs Made During the Avoidance Maneuver	ABS	Practice	62	3.8	1.6	1	7	0.9058
		No Practice	57	3.8	1.4	1	7	
	Conventional	Practice	30	4.3	1.3	2	8	0.4137
		No Practice	30	4.0	1.2	1	7	

4.7.4. Braking Behavior by Braking Practice

Results for braking behavior as a function of braking practice for dry pavement are listed in Table 55.

Table 55. Braking behavior by braking practice for dry pavement (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	Brake System	Braking Practice	N	Mean	SD	Min	Max	P-value
Time to Initial Brake Input (s)	ABS	Practice	64	1.44	0.29	0.88	2.29	0.0398
		No Practice	63	1.54	0.31	0.61	2.20	
	Conventional	Practice	32	1.45	0.29	0.84	2.21	0.0713
		No Practice	32	1.58	0.29	1.04	2.34	
Throttle to Brake Application Transition Time (s)	ABS	Practice	64	0.26	0.12	-0.14	0.51	0.0072
		No Practice	61	0.35	0.22	-0.13	0.79	
	Conventional	Practice	30	0.30	0.16	0.13	0.80	0.5622
		No Practice	32	0.33	0.18	0.10	0.93	
Throttle to Maximum-Brake Application Transition Time (s)	ABS	Practice	64	1.06	0.47	0.28	2.45	0.1194
		No Practice	63	1.22	0.66	0.29	4.04	
	Conventional	Practice	31	1.30	0.87	0.26	3.82	0.1350
		No Practice	32	1.04	0.48	0.24	2.30	
Time to Maximum Brake Input (s)	ABS	Practice	64	2.23	0.41	1.30	3.37	0.1654
		No Practice	63	2.33	0.43	1.35	3.51	
	Conventional	Practice	32	2.37	0.66	1.12	4.14	0.5316
		No Practice	32	2.29	0.39	1.51	3.22	
Maximum Brake Pedal Force (lbs)	ABS	Practice	64	65	28	3	170	0.9319
		No Practice	63	65	32	9	188	
	Conventional	Practice	32	64	34	14	182	0.5784
		No Practice	32	60	32	9	150	
Brake Pedal Application Duration (s)	ABS	Practice	64	2.15	1.13	0.01	5.15	0.7248
		No Practice	63	2.24	1.14	0.04	5.39	
	Conventional	Practice	32	2.26	1.65	0.01	8.90	0.1274
		No Practice	32	1.71	1.25	0.01	4.94	

Wheel Lockup and ABS Activations by Braking Practice. Data describing observed cases of wheel lockup with conventional brakes as well as ABS activation rates are given in Table 56.

Table 56. Percentage of conventional brake system wheel lockups and ABS activations by braking practice for dry pavement.

Brake System	Braking Practice	% Activated ABS or Locked Wheels	P-Value	% Did Not Activate ABS or Lock Wheels
Conventional	Practice	34	0.2660	66
	No Practice	22		78
ABS	Practice	36	0.3440	64
	No Practice	28		72

Missed Brake Pedal Applications by Braking Practice. For subjects in the ABS condition on dry pavement, 16 of 62 subjects (26 percent) who received practice and 14 of 58 subjects (24 percent) who did not receive practice missed the brake pedal at least once during the crash avoidance maneuver. On dry pavement, 8 of 29 subjects (28 percent) in the conventional brake system condition who received practice and 11 of 31 subjects (35 percent) who did not receive braking practice missed the brake pedal one or more times during their crash avoidance maneuver. Sample sizes varied in these analyses due to the lack of video data for twelve subjects.

Data describing rates of missed brake pedal applications and non-standard brake pedal applications (e.g., left-footed or two-footed braking) observed during subjects' crash avoidance maneuvers are provided as percentages in Table 57.

Table 57. Percentage of missed and non-standard brake pedal application techniques by brake system and braking practice.

Brake System	Braking Practice	Missed Brake Pedal Once	Missed Brake Pedal Twice	Non-Standard Brake Pedal Application
Conventional	Practice	28	0	7
	No Practice	35	0	6
ABS	Practice	26	2	11
	No Practice	24	10	3

4.7.5. Deceleration by Braking Practice

Mean maximum deceleration on dry pavement did not differ significantly as a function of braking practice. Results for this measure are presented in Table 58.

Table 58. Deceleration results by braking practice for dry pavement.

Brake System	Braking Practice	N	Mean	SD	Min	Max	P-Value
Conventional	Practice	32	0.74	0.23	0.11	1.07	0.1286
	No Practice	32	0.65	0.27	0.06	1.06	
ABS	Practice	64	0.74	0.24	0.01	1.15	0.4840
	No Practice	64	0.72	0.24	0.11	1.12	

4.7.6. Road Departures by Braking Practice

Full Road Departures by Braking Practice. As stated earlier, two subjects in the ABS condition fully departed the roadway in the dry pavement study. One of these road departures involved a subject who had received braking practice and the other involved a subject who did not receive braking practice.

Partial Road Departures by Braking Practice. Two partial road departures were observed on dry pavement, one with ABS and one with conventional brakes. Both received braking practice.

4.7.7. Crashes by Braking Practice

Thirty-one percent of 64 subjects in the braking practice condition (includes subjects who received instruction and subjects who did not receive instruction) with ABS collided with the incursion vehicle on dry pavement. For those not receiving braking practice, 44 percent of 64 subjects with ABS crashed. Fifty percent of 32 subjects in the braking practice condition with conventional brakes collided with the incursion vehicle on dry pavement. For those not receiving braking practice, 41 percent of 32 subjects with conventional brakes crashed. These differences were not statistically significant. However, significant results were found for subjects who received practice but no ABS instruction as highlighted in Section 4.7.

Results for crashes as a function of brake system, braking practice, and whether or not subjects activated ABS or locked wheels with conventional brakes are listed in Table 59. In the dry pavement study, for subjects in the ABS condition who received braking practice and who activated ABS crashed 39 percent versus 27 percent for those who did not activate ABS (X^2 = 1.038, p = 0.308). For subjects in the ABS condition who did not receive braking practice, those who activated ABS crashed 33 percent versus 48 percent for those who did not activate ABS (X^2 = 1.104, p = 0.293). Subjects in the conventional brake system condition who received braking practice and experienced wheel lockup crashed 64 percent of the time whereas 43 percent of those who did not experience wheel lockup crashed (X^2 = 1.247, p = 0.264). For conventional brake system subjects who did not receive braking practice, 43 percent who locked wheels crashed versus 40 percent crashes for those who did not lock the wheels (X^2 = 0.019, p = 0.892).

Table 59. Percent ABS activations, cases of conventional brake system wheel lockup, and associated crashes by braking practice for the dry pavement condition.

Brake System	**Braking Practice**	% Activated ABS or Locked Wheels	% Crashed	% Did Not Activate ABS or Lock Wheels	% Crashed
Conventional	Practice	34	64	66	43
	No Practice	22	43	78	40
ABS	Practice	36	39	64	27
	No Practice	28	33	72	48

4.8. INTERACTION OF INSTRUCTION AND PRACTICE

Table 60 shows crash results based on combinations of the two training methods of instruction and practice as well as by brake system to illustrate the interaction effects associated with these independent variables.

For subjects who received practice but no ABS instruction in the dry pavement study, those with ABS crashed 25 percent of the time while those in the conventional brake system condition crashed 50 percent of the time. Using a Chi-Square test, this difference was found to be statistically significant (X^2 = 4.267, p = 0.039) as indicated in Table 60.

Table 60. Crash results (in percentages) based on the two training methods of instruction and practice, and by brake system. (Value pairs marked with asterisks are significantly different.)

Brake System	**Instruction**	**Practice**	**Percent Crashes - Dry**	**Percent Crashes -Wet**
Conventional	NA	No Practice	41	100**, ***
	NA	Practice	50*	NA
ABS	No Instruction	No Practice	47	50**
	Instruction	Practice	38	NA
	Instruction	No Practice	41	67***
	No Instruction	Practice	25*	NA

4.9. TIME-TO-INTERSECTION (TTI)

In the dry pavement study, two TTI values were used (see experimental design section for TTI definition). Half of the subjects (96/192) were in the 2.5 second TTI condition and the other half were in the 3.0 second condition. In the wet pavement study, the 2.5 second TTI was the only condition used, therefore, TTI was not an independent variable in the wet study. This was done since the alterations of testing equipment to accommodate the two TTI values were too difficult to perform on wet pavement with accuracy and efficiency. Since no comparisons within the wet pavement condition could be made for TTI, wet pavement results are not listed throughout this section. However, a comparison table of the wet versus dry pavement study results for the 2.5 second condition is included at the end of this section.

4.9.1. Scenario Entrance Speed by TTI

Scenario entrance speed did not differ significantly by TTI. Results for scenario entrance speed as a function of TTI for dry pavement are listed in Table 61. There was no difference between ABS and conventional subjects within either TTI condition.

Table 61. Scenario entrance speed by TTI.

TTI (s)	Pavement	N	Mean	SD	Min	Max	P-Value
2.5	Dry	96	44	1	27	50	0.2770
3.0	Dry	96	44	0	40	48	

4.9.2. Reaction Times by TTI

Reaction Time by TTI. Reaction time values by time to intersection are listed in Table 62. Reaction time for the 2.5 second TTI condition was significantly shorter than that found for the 3.0 second condition.

Time to Throttle Release by TTI. Time to throttle release was found to be significantly longer in the 3.0 second TTI condition. Results for this measure as a function of TTI are listed in Table 62.

Table 62. Reaction times by TTI for dry pavement.

MEASURE	TTI	N	Mean	SD	Min	Max	P-value
Reaction Time (s)	2.5 - Dry	93	1.10	0.28	0	1.93	0.0007
	3.0 - Dry	96	1.23	0.32	0.68	2.14	
Time to Throttle Release (s)	2.5 - Dry	92	1.13	0.24	0.55	1.93	0.0010
	3.0 - Dry	96	1.25	0.32	0.80	2.14	

4.9.3. Steering Behavior by TTI

Results for steering behavior as a function of time to intersection (TTI) are listed in Table 63. TTI was found to have significant effects on time to initial steering input, time to maximum steering input, and total number of steering inputs.

Table 63. Steering behavior by TTI (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	TTI	Dry					
		N	Mean	SD	Min	Max	P-value
Time to Initial Steering Input (s)	2.5	89	1.45	0.50	0	3.71	0.0001
	3.0	92	1.84	0.58	0.68	4.26	
Initial Steering Input Magnitude (degrees)	2.5	87	30	34	6	179	0.9900
	3.0	92	27	34	6	276	
Avoidance Steering Input Magnitude (degrees)	2.5	88	52	41	2	179	0.4845
	3.0	92	54	46	6	271	
Avoidance Steering Input Range (degrees)	2.5	86	54	43	7	179	0.6728
	3.0	90	57	49	7	276	
Time to Maximum Steering Input (s)	2.5	90	2.38	0.67	1.17	4.29	0.0001
	3.0	92	3.05	0.88	1.25	6.72	
Maximum Steering Input Magnitude (degrees)	2.5	89	56	42	7	180	0.5057
	3.0	92	58	48	6	271	
Maximum Steering Input Rate (degrees/s)	2.5	90	277	220	35	1159	0.4651
	3.0	92	248	178	30	869	
First Lane Recovery Steering Input Range (degrees)	2.5	86	97	70	10	320	0.4742
	3.0	80	104	71	5	418	
Total Number of Steering Inputs Made During the Avoidance Maneuver	2.5	87	4.2	1.3	1	7	0.0374
	3.0	92	3.7	1.5	1	8	

4.9.4. Braking Behavior by TTI

Results for braking behavior as a function of TTI are shown in Table 64.

Table 64. Braking behavior by TTI (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	TTI	Dry					
		N	Mean	SD	Min	Max	P-value
Time (s) to Initial Brake Input	2.5	95	1.44	0.26	0.61	2.11	0.0014
	3.0	96	1.56	0.32	1.05	2.34	
Throttle to Brake Application Transition Time (s)	2.5	91	0.31	0.16	-0.13	0.78	0.9308
	3.0	96	0.31	0.19	-0.14	0.93	
Throttle to Maximum-Brake Application Transition Time (s)	2.5	94	1.12	0.66	0.24	4.04	0.6663
	3.0	96	1.18	0.58	0.26	2.91	
Time (s) to Maximum Brake Input	2.5	95	2.17	0.40	1.12	3.51	0.0001
	3.0	96	2.42	0.49	1.30	4.14	
Maximum Brake Pedal Force (lbs)	2.5	95	68	35	3	188	0.0380
	3.0	96	60	27	9	170	
Brake Pedal Application Duration (s)	2.5	95	1.99	1.41	0.01	8.90	0.3076
	3.0	96	2.25	1.07	0.01	5.15	

4.9.5. Deceleration by TTI

An analysis was conducted to determine the mean maximum deceleration achieved by subjects as a function of time-to-intersection. In the dry pavement study, the mean maximum deceleration was 0.73 g (SD 0.25, max 1.13, min 0.06) for subjects in the 2.5 second TTI condition and 0.71 g (SD 0.24, max 1.15, min 0.01) for subjects in the 3.0 second TTI condition ($p = 0.2189$).

These data were also examined by brake system for subjects in the dry pavement study. For the 2.5 second TTI condition, the mean maximum deceleration for subjects in the ABS condition was 0.73 g (SD 0.25, max 1.13, min 0.08) versus 0.74 g (SD 0.24, max 1.06, min 0.06) for subjects with conventional brakes (p = 0.1999). For subjects in the 3.0 second TTI condition, the mean maximum deceleration was 0.73 g (SD 0.24, max 1.15, min 0.01) for subjects in the ABS condition versus 0.66 g (SD 0.25, max 1.07, min 0.06) for subjects with conventional brakes (p = 0.1107).

4.9.6. Road Departures by TTI

Full Road Departures by TTI. As stated earlier, two subjects in the ABS condition departed the roadway fully in the dry pavement study. One of these road departures was experienced by a subject in the 2.5 second TTI condition and the other involved the 3.0 second TTI condition.

Partial Road Departures by TTI. Two partial road departures were observed in the dry pavement study, one in the 2.5 second TTI condition and the other in the 3.0 second TTI condition.

4.9.7. Crashes by TTI

Fifty-one percent of the 96 subjects in the 2.5 second TTI condition collided with the incursion vehicle on dry pavement. In the 3.0 second TTI condition, 29 percent of the 96 subjects crashed on dry pavement. The difference was statistically significant [$X^2 = 9.562$, $p = 0.002$].

4.9.8. Comparison of the 2.5 second TTI condition: Dry versus Wet

A comparison table of the 2.5 second TTI condition dependent variables of the wet versus dry pavement conditions is as follows in Table 65.

Table 65. Comparison of selected measures for the 2.5 second TTI condition dry versus wet pavement.

Dependent Variable	Dry Pavement (n = 96 Subjects)	Wet Pavement (n = 53 Subjects)
Mean Magnitude of Avoidance Steering Input	52 degrees	74 degrees
Mean Maximum Avoidance Steering Rate	277 degrees / second	294 degrees / second
Mean Maximum Brake Pedal Force	67 pounds	68 pounds
Road Departures (Full)	1/96 Subjects	0/53 Subjects
Road Departures (Partial)	1/96 Subjects	1/53 Subjects
Crashes with Incursion Vehicle	51%	72%

4.10. GENDER

Gender was approximately balanced throughout all conditions in this study (dry pavement 104 males, 88 females, wet pavement 26 males, 27 females). Overall, crash avoidance behavior observed for male subjects was characterized by inputs of higher magnitudes than females. However, most of the differences observed between genders were not significant.

4.10.1. Scenario Entrance Speed by Gender

Results for scenario speed as a function of gender are listed in Table 66. Scenario entrance speed did not differ significantly by gender. There was no difference between ABS and conventional subjects within either gender.

Table 66. Scenario entrance speed by gender.

Pavement	Gender	N	Mean	SD	Min	Max
Dry	Male	104	44	2	39	50
	Female	88	44	2	27	47
Wet	Male	26	34	1	31	37
	Female	27	34	2	28	36

4.10.2. Reaction Times by Gender

Reaction Time by Gender. Results for reaction time as a function of gender are presented in Table 67.

Time to Throttle Release by Gender. Results for time to throttle release as a function of gender are listed in Table 67.

Table 67. Reaction times by gender for dry and wet pavements.

MEASURE	Pavement	Gender	N	Mean	SD	Min	Max	P-value
Reaction Time (s)	Dry	Male	101	1.19	0.30	0.55	1.97	0.2096
		Female	88	1.14	0.31	0	2.14	
	Wet	Male	25	1.15	0.26	0.84	1.80	0.1350
		Female	26	1.04	0.28	0.20	1.41	
Time (s) to Throttle Release	Dry	Male	100	1.21	0.30	0.55	2.01	0.4322
		Female	88	1.17	0.27	0.80	2.14	
	Wet	Male	25	0.16	0.26	0.84	1.80	0.2475
		Female	26	1.07	0.29	0.20	1.60	

4.10.3. Steering Behavior by Gender

Results for steering behavior as a function of gender and pavement condition are summarized in Table 67.

Avoidance Steering Input Magnitude by Gender. Figures 40 and 41 contain frequency distributions of avoidance steering input magnitudes by gender.

Maximum Steering Input Rate by Gender. Mean maximum steering input rate results are presented in Table 68. Figures 42 and 43 contain frequency distributions of avoidance steering input rates by gender.

First Lane Recovery Steering Input Range by Gender. Values for mean first lane recovery steering input range varied significantly ($p = 0.0078$) by gender with the mean for males being 114 degrees (SD 75, max 418, min 6) and for females, 85 degrees (SD 62, max 246, min 5). Wet pavement values for mean first lane recovery steering input range nearly varied significantly ($p = 0.0644$). The mean first lane recovery steering input range on wet pavement for males was 121 degrees (SD 85, max 324, min 7) and for females was 83 degrees (SD 58, max 201, min 11).

Total Number of Steering Inputs Made During the Avoidance Maneuver by Gender. Results for mean total number of steering inputs during the crash avoidance maneuver were not found to be significantly different by gender for either pavement condition. In the dry pavement study, the mean number of steering inputs made by both males and females during the avoidance maneuver was 3.9 inputs (SD 1.4 males, 1.5 females, max 7, min 1, max 8, min 1). In the wet pavement study, the mean number of steering inputs made by males during the avoidance maneuver was 4.6 inputs (SD 1.9, max 11, min 2) and for females was 4.7 inputs (SD 1.3, max 8, min 2).

Table 68. Steering behavior by gender (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	GENDER	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Steering Input	Male	97	1.64	0.53	0.92	4.26	0.8171	26	1.49	0.41	0.91	2.71	0.4240
	Female	84	1.66	0.62	0	3.10		26	1.39	0.43	0.69	2.45	
Initial Steering Input Magnitude (degrees)	Male	95	30	31	6	179	0.6424	26	28	24	7	90	0.4600
	Female	84	28	37	6	276		26	34	31	8	109	
Avoidance Steering Input Magnitude (degrees)	Male	96	59	44	3	197	0.0256	26	77	62	7	251	0.7892
	Female	84	45	41	2	271		26	72	67	10	289	
Avoidance Steering Input Range (degrees)	Male	92	66	47	7	187	0.0012	26	72	74	7	302	0.7867
	Female	84	44	42	7	276		26	78	87	7	400	
Time (s) to Maximum Steering Input	Male	98	2.73	0.80	1.17	6.72	0.8594	26	2.61	0.75	1.70	5.45	0.5423
	Female	84	2.71	0.90	1.18	5.99		26	2.78	1.14	1.04	5.85	
Maximum Steering Input Magnitude (degrees)	Male	97	63	45	6	221	0.0582	26	78	61	7	251	0.8105
	Female	84	51	45	7	271		26	74	64	10	289	
Maximum Steering Input Rate (degrees / second)	Male	97	306	222	30	1159	0.0016	26	321	276	33	1335	0.4307
	Female	85	213	159	30	640		27	269	193	41	801	
First Lane Recovery Steering Input Range (degrees)	Male	88	114	75	6	418	0.0078	26	121	85	7	324	0.0644
	Female	78	85	62	5	246		26	83	58	11	201	
Total Number of Steering Inputs Made During the Avoidance Maneuver	Male	95	3.9	1.4	1	7	0.9483	26	4.6	1.9	2	11	0.7984
	Female	84	3.9	1.5	1	8		26	4.7	1.3	2	8	

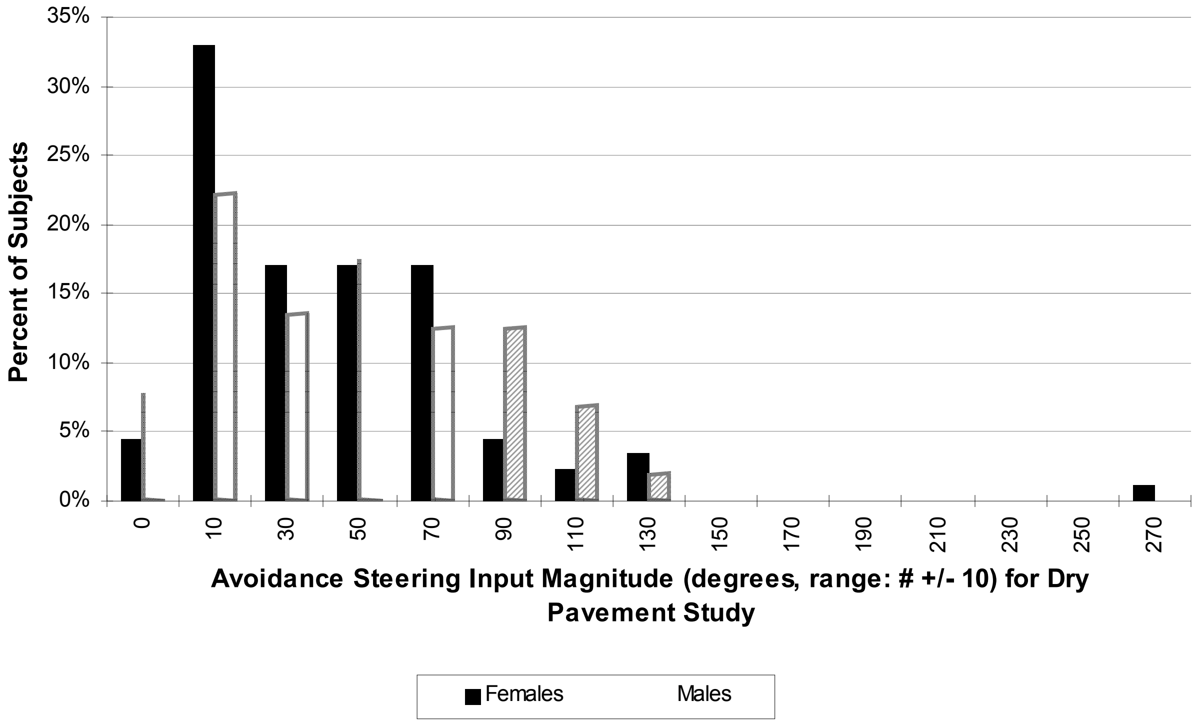

Figure 40. Frequency distribution of avoidance steering input magnitudes by gender for dry pavement.

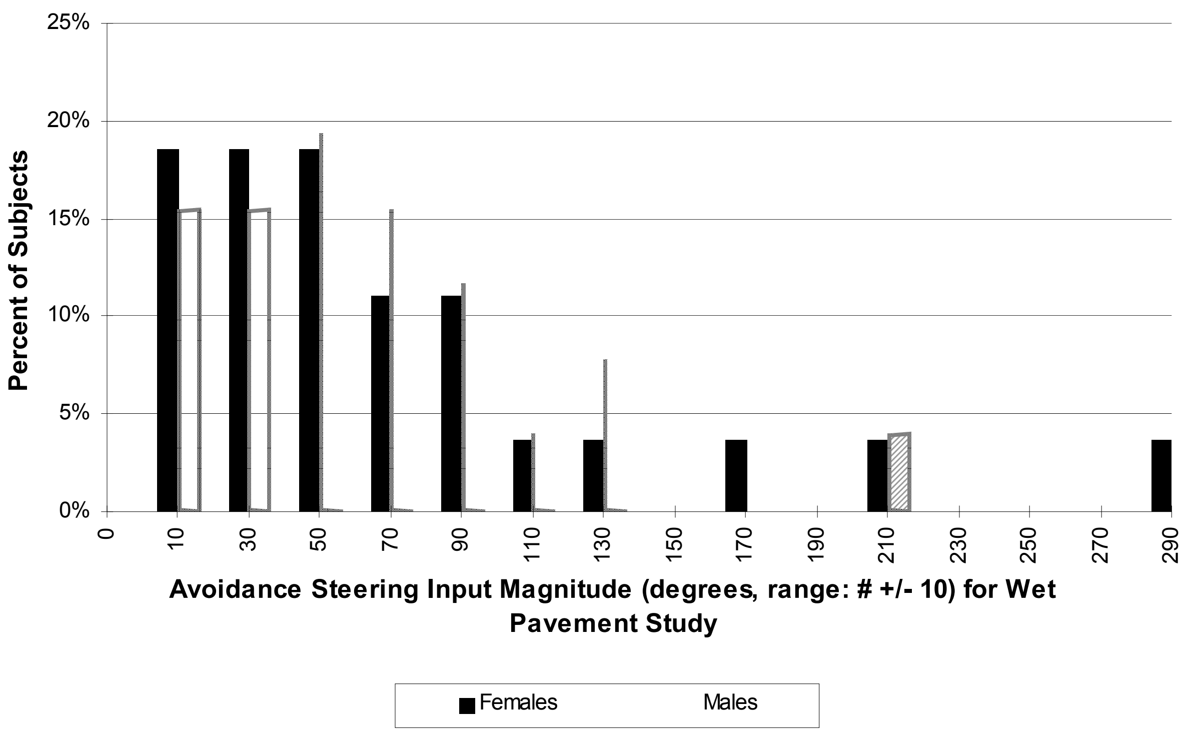

Figure 41. Frequency distribution of avoidance steering input magnitudes by gender for wet pavement.

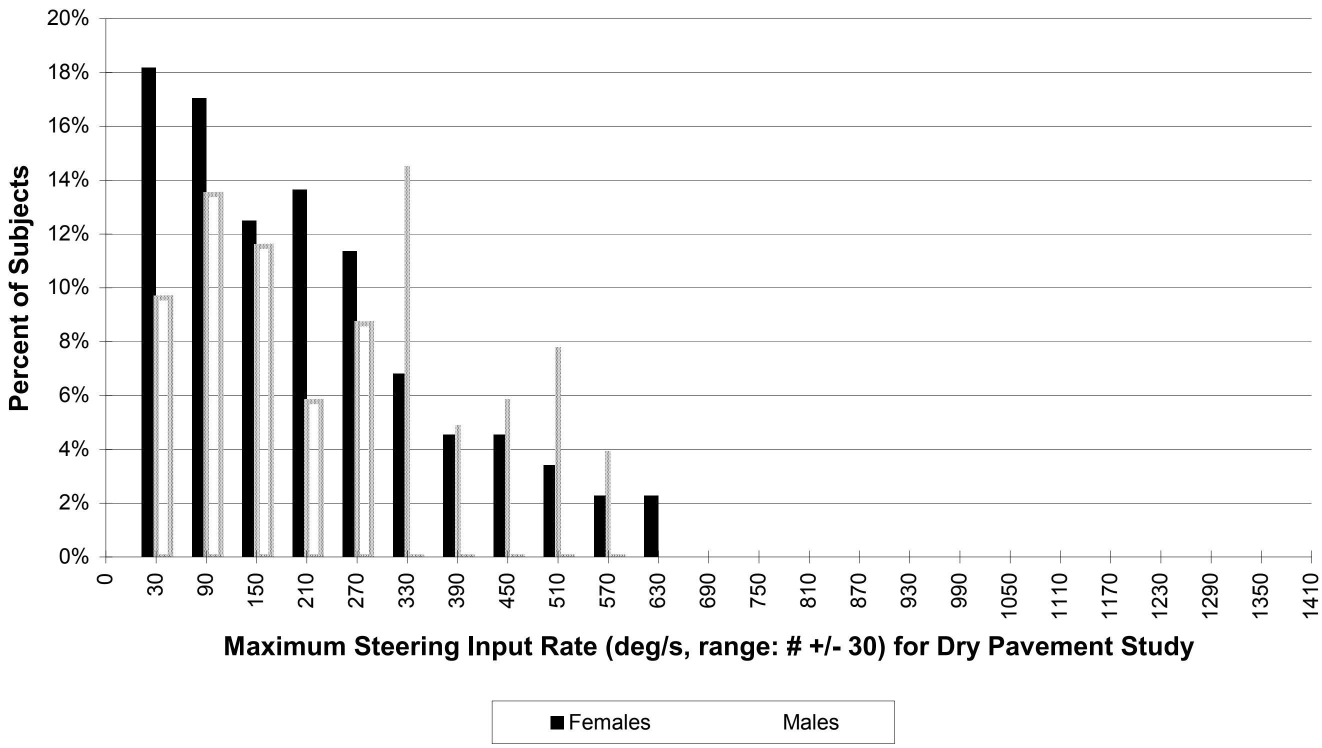

Figure 42. Frequency distribution of avoidance steering input rate by gender for dry pavement.

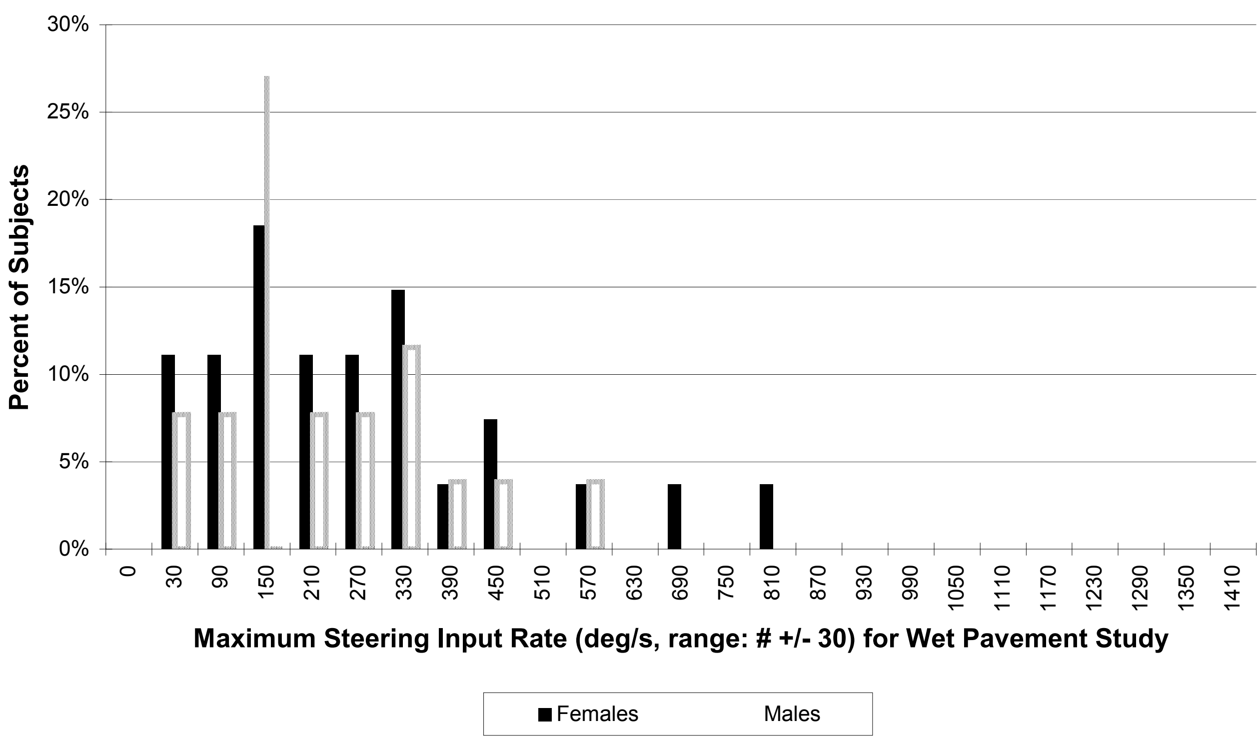

Figure 43. Frequency distribution of avoidance steering input rate by gender for wet pavement.

4.10.4. Braking Behavior by Gender

Results for braking behavior by gender and pavement condition are listed in Table 69.

Table 69. Braking behavior by gender (P-values correspond to the comparison of the 2 rows they span. Non-significant results are denoted by p-values that are shaded.)

MEASURE	GENDER	Dry						Wet					
		N	Mean	SD	Min	Max	P-value	N	Mean	SD	Min	Max	P-value
Time (s) to Initial Brake Input	Male	104	1.48	0.30	0.61	2.21	0.5318	26	1.47	0.37	1.05	2.41	0.3003
	Female	87	1.51	0.29	1.04	2.34		26	1.37	0.29	0.88	2.38	
Throttle to Brake Transition Time (s)	Male	100	0.28	0.18	-0.14	0.80	0.0287	25	0.31	0.26	0.05	1.19	0.9423
	Female	87	0.34	0.16	0.14	0.93		26	0.30	0.32	0.01	1.34	
Throttle to Maximum-Brake Transition Time (s)	Male	103	1.14	0.69	0.24	4.04	0.7145	25	1.20	0.62	0.34	3.18	0.7462
	Female	87	1.17	0.54	0.29	2.91		26	1.14	0.74	0.29	4.18	
Time (s) to Maximum Brake Input	Male	104	2.26	0.45	1.12	3.81	0.2457	26	2.35	0.57	1.54	4.18	0.4585
	Female	87	2.34	0.48	1.39	4.14		27	2.22	0.71	1.34	5.22	
Maximum Brake Pedal Force (lbs)	Male	104	66	34	3	188	0.2357	26	74	48	13	240	0.2796
	Female	87	62	28	9	170		27	62	31	12	134	
Brake Pedal Application Duration (s)	Male	104	2.23	1.27	0.01	8.90	0.1879	26	2.38	2.16	0.16	7.70	0.8212
	Female	87	1.99	1.24	0.01	5.39		27	2.51	1.90	0.11	6.31	

Wheel Lockup and ABS Activations by Gender. In the dry pavement study, 35 percent of the males in the ABS condition activated ABS and 31 percent locked the wheels in the conventional condition. In the dry pavement study, 28 percent of the females in the ABS condition activated ABS and 25 percent locked the wheels in the conventional condition. In the wet pavement study, 100 percent of the males in the ABS condition activated ABS and 100 percent locked the wheels in the conventional condition. In the wet pavement study, 95 percent of the females in the ABS condition activated ABS and 86 percent locked the wheels in the conventional condition.

Missed Brake Pedal Applications by Gender. In the dry pavement study, 19 percent of the males missed the brake pedal once, another one percent missed the brake pedal twice, and 10 percent had a non-standard brake pedal application technique. In the dry pavement study, 37 percent of the females missed the brake pedal once, another 7 percent missed the brake pedal twice, and 4 percent had a non-standard brake pedal application technique. In the dry pavement study, the difference between males and females who missed the brake pedal once was statistically significant [$X^2 = 7.961$, $p = 0.005$]. In the wet pavement study, 4 percent of the males missed the brake pedal once. In the wet pavement study, 12 percent of the females missed the brake pedal once, and 4 percent had a non-standard brake pedal application technique. The wet pavement differences were not statistically significant.

4.10.5. Deceleration by Gender

An analysis was conducted to determine the average maximum deceleration achieved by subjects as a function of gender. Overall, the mean maximum deceleration was 0.68 g (SD 0.25, max 1.12, min 0.03) for males and 0.63 g (SD 0.25, max 1.15, min 0.004) for females ($p = 0.0924$).

These data were also examined by pavement condition. In the dry pavement study, the mean maximum deceleration was 0.74 g (SD 0.24, max 1.12, min 0.03) for males and 0.69 g (SD 0.25, max 1.15, min 0.01) for females (p = 0.1144). On wet pavement, the mean observed maximum deceleration was 0.45 g (SD 0.10, max 0.67, min 0.17) for males and 0.45 g (SD 0.11, max 0.57, min 0.004) for females (p = 0.9203).

4.10.6. Road Departures by Gender

Full Road Departures. Of the two subjects in the dry pavement study who drove completely off the road to avoid a crash, the subject who departed the road to the right was a male, while the subject who departed the road to the left was a female.

Partial Road Departures. Of the three partial road departures observed in these studies, two occurred in the dry pavement study and one in the wet pavement study. In the dry pavement study, a male subject made the right side partial road departure and a female made the left side partial road departure. The partial road departure in the wet pavement study was a female.

4.10.7. Crashes by Gender

Crash rates as a function of pavement condition, brake system, and gender are listed in Table 70.

Table 70. Crashes as a function of gender, brake system, and pavement condition

BRAKE SYSTEM	GENDER	Percent Crashes - Dry	Percent Crashes - Wet
Overall	Male	40	77
	Female	40	67
Conventional	Male	50	100
ABS	Male	35	62.5
Conventional	Female	39	100
ABS	Female	40	55

4.11. INTERACTION OF GENDER AND BRAKE SYSTEM

The analysis of crash percentages as a function of gender, brake system, and pavement condition revealed that males crashed significantly less with ABS than with conventional brakes on wet pavement (X^2 = 4.875, p = 0.027). Sixty-three percent of males in the ABS condition crashed versus 100 percent of those in the conventional brake system condition, as shown in Table 70. This difference for females was also significantly less with ABS (55 percent) than with conventional brakes (100 percent) on wet pavement (X^2 = 4.725, p = 0.030).

On dry pavement, 35 percent of males in the ABS condition crashed while 50 percent of males with conventional brakes crashed. Forty percent of females in the ABS condition crashed while 39 percent of females in the conventional brake system condition crashed. These differences were not statistically significant.

5.0 EXAMINATION OF OBSERVED ROAD DEPARTURES

Five road departures were observed in this study. Two full road departures (all four wheels) and two partial road departures (one or two wheels) were seen in the dry pavement study. In the wet pavement study, there was only one partial road departure. The subjects' vehicle control inputs are described using the parameters of applied brake pedal force, wheel speeds, vehicle travel speed, steering wheel angle, and steering wheel rate.

5.1. FULL ROAD DEPARTURES

5.1.1. Full Road Departure #1

Figure 44 depicts the response of a female subject in the dry pavement study who fully departed the road to the left. This subject was driving the ABS-equipped vehicle with heavy brake pedal feedback (Taurus) in the 2.5 second TTI condition. The subject had not received ABS instruction or braking practice.

The subject was driving at a speed of 45 mph when the incursion vehicle began to move into the intersection. The subject was noticeably startled by the incursion. Her initial reaction time was 1.04 seconds at which time she released the throttle. Next, she made a quick steering input of 92 degrees to the left. The subject then braked at approximately 1.36 seconds after the incursion start with her maximum brake pedal force reaching 51 pounds. The subject crossed the intersection diagonally and drove completely off road to the left, past the crossing road. Approximately 2.02 seconds after the incursion initiation, the subject changed steering direction from left to right in an attempt to recover lane position. At about the same time as the steering direction change, a build and then a dump can be observed in the right side brake line pressure data over a period of about 3 seconds during which applied brake pedal force is shown to be consistently decreasing (as shown in Figure 45). This brake system behavior suggests the occurrence of ABS activation. However, evidence of ABS activation cannot be seen in the front wheel speed data channels. The vehicle's ABS was activated briefly after the subject had already driven the vehicle fully off the road. The activation took place during the subject's lane recovery steering input in which she attempted to maneuver the vehicle back onto the roadway. At approximately 4.76 seconds the subject released the brake pedal and steering inputs leveled out indicating successful lane position recovery.

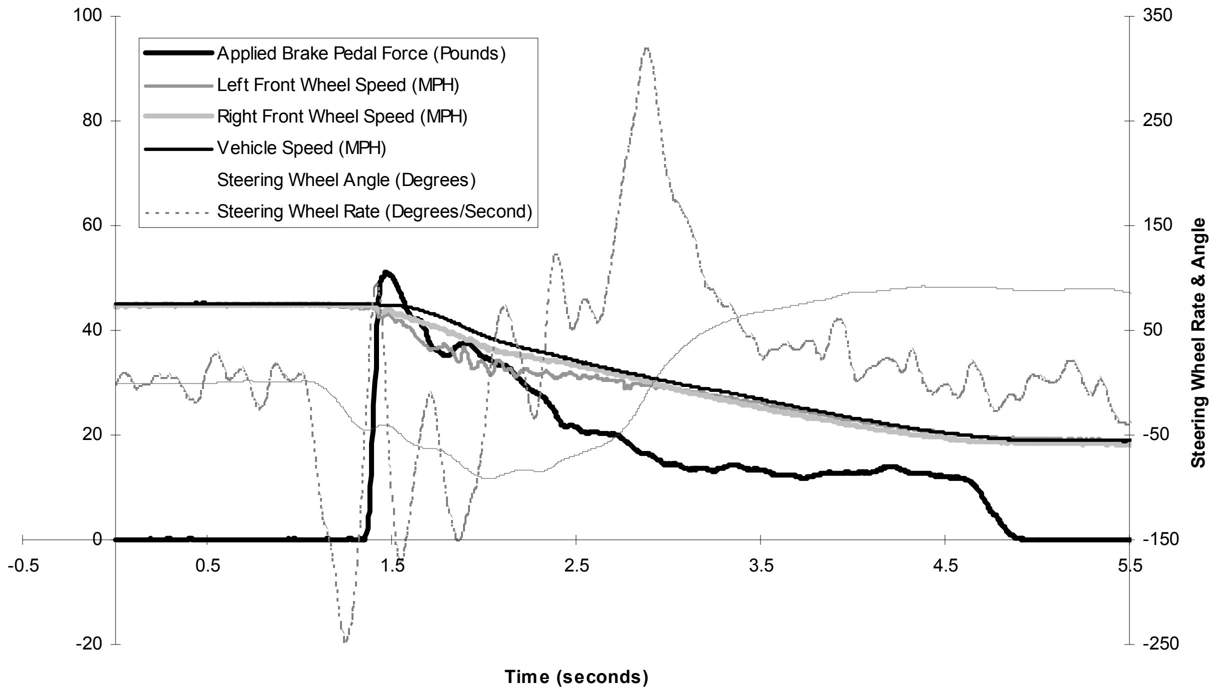

Figure 44. Illustration of the avoidance maneuver of a female subject that ended in a four-wheel, left side road departure with ABS on dry pavement.

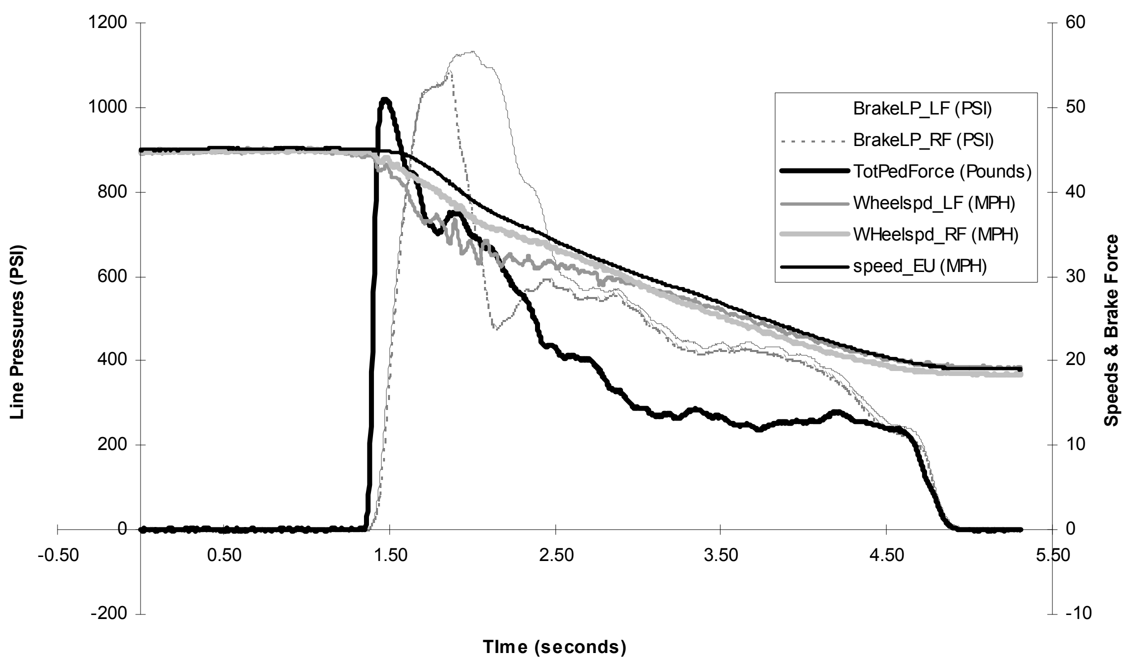

Figure 45. Measured applied brake pedal force and associated brake line pressures during an avoidance maneuver in which the vehicle fully departed the roadway and ABS activation is believed to have occurred.

5.1.2. Full Road Departure #2

Figure 46 depicts the response of a male subject in the dry pavement study who fully departed the road to the right after hitting the rear of the incursion vehicle (time of incursion was 4.43 seconds). This subject was assigned the ABS condition with heavy brake pedal feedback (Taurus) in the 3.0 second TTI condition. The subject had received braking practice, but did not receive ABS instruction.

This male subject was driving at a speed of 45 mph when the incursion vehicle began to move into the intersection. His initial reaction time was 1.47 seconds at which time he released the throttle. At 1.59 seconds after the start of the incursion, the subject initiated a steering input of 197 degrees to the right. The subject applied the brakes 1.66 seconds after the incursion. The subject's applied brake pedal force reached a quick maximum of 72 pounds during the beginning of the crash avoidance maneuver. Shortly after this subject applied the brakes, oscillations occurred in all four brake line pressure channels in the sensor data, as shown in Figure 47, signaling ABS activation. This activation lasted for nearly 3 seconds. While braking, the subject collided with the rear of the incursion vehicle and drove over a collapsible stop sign. The subject then brought the vehicle to a stop off to the right side of the road past the intersection. ABS does not appear to have contributed to this road departure.

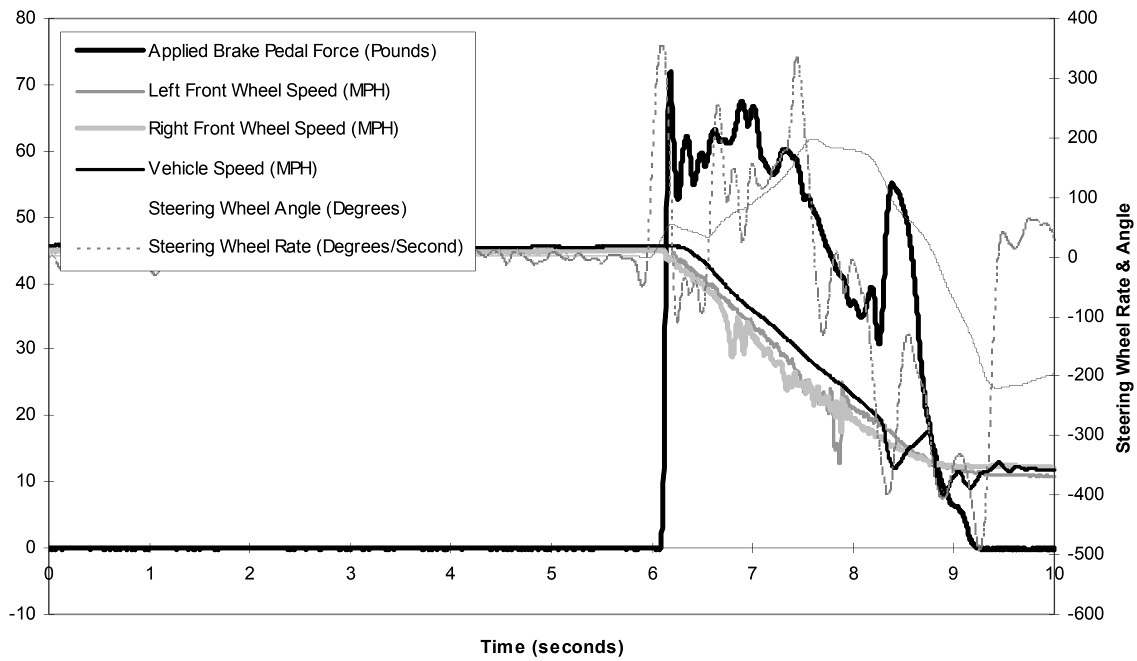

Figure 46. Illustration of the avoidance maneuver of a male subject that ended in a four-wheel, right side road departure with ABS on dry pavement.

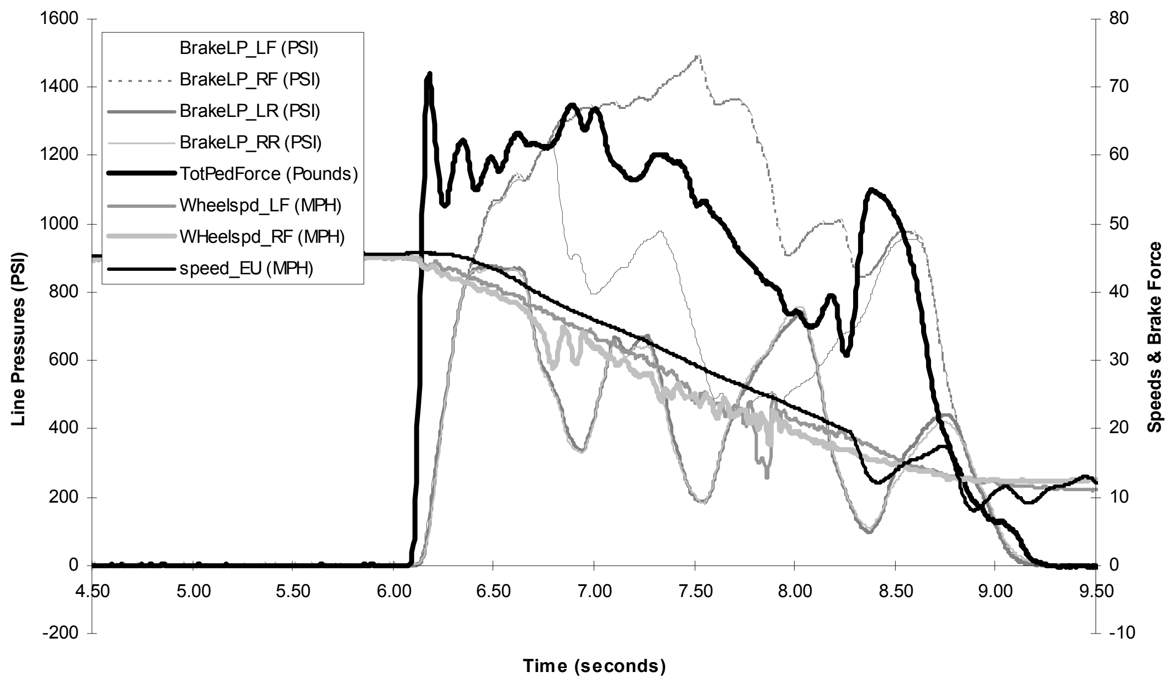

Figure 47. Measured applied brake pedal forces and associated brake line pressures during an avoidance maneuver in which the vehicle fully departed the roadway and ABS activation is believed to have occurred.

5.2. PARTIAL ROAD DEPARTURES

5.2.1. Partial Road Departure #1

Figure 48 depicts the response of a male subject in the dry pavement study who partially departed the road to the right after colliding with the incursion vehicle. He was driving the Ford Taurus test vehicle configured with conventional brakes under the 3.0 second TTI condition and did receive braking practice.

This male subject was driving at a speed of 45 mph when the incursion vehicle began to move into the intersection. His initial reaction time was 1.18 seconds at which time he released the throttle. At 1.37 seconds after the start of the incursion, the subject applied the brakes using his left foot. The subject's applied brake pedal force reached a quick maximum of 51 pounds during the beginning of the crash avoidance maneuver as shown in Figure 49. At approximately 1.43 seconds past the start of the incursion, the subject initiated a steering input of 8 degrees to the left. At 1.53 seconds after the start of the incursion, the subject changed steering directions by initiating a steering input to the right reaching a maximum handwheel angle of 195 degrees. At 2.54 seconds past the start of the incursion, the right front wheel locked followed by the left front wheel at 3.02 seconds. The subject's steering input toward the incursion vehicle caused him to strike it, causing it to break in half. The subject stopped the vehicle 4.6 seconds after the start of the incursion with the right front wheel off the road.

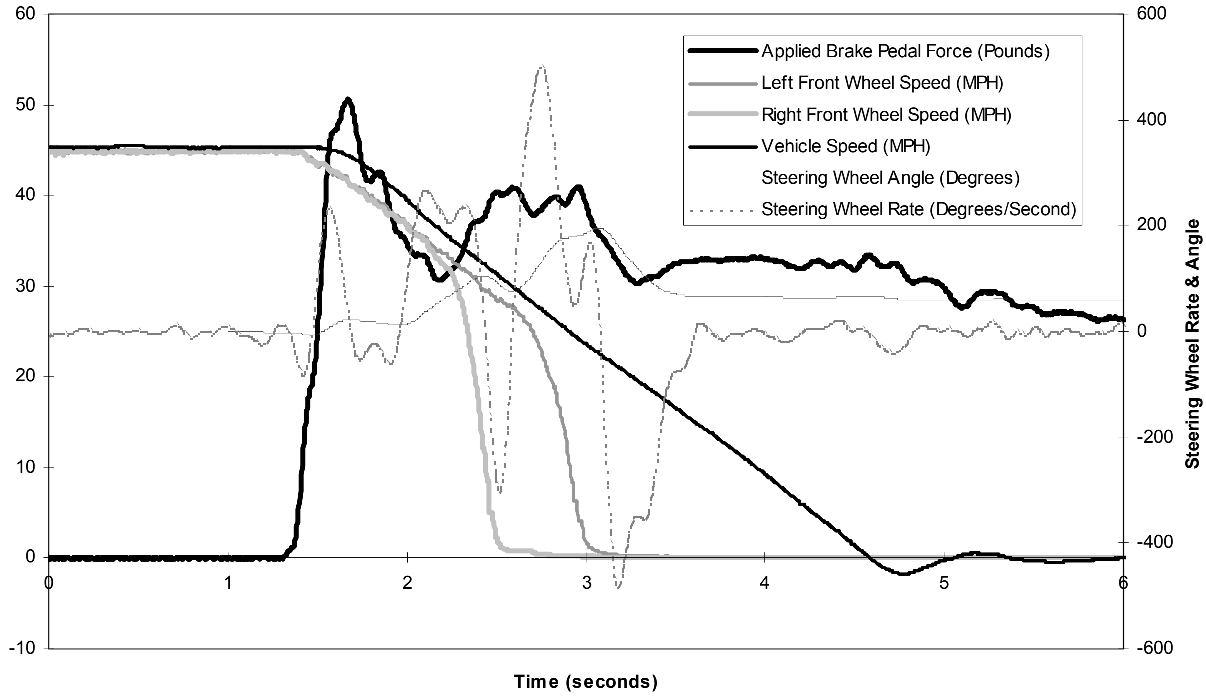

Figure 48. Illustration of the avoidance maneuver of a male subject that ended in a two-wheel, right side road departure with conventional brakes on dry pavement.

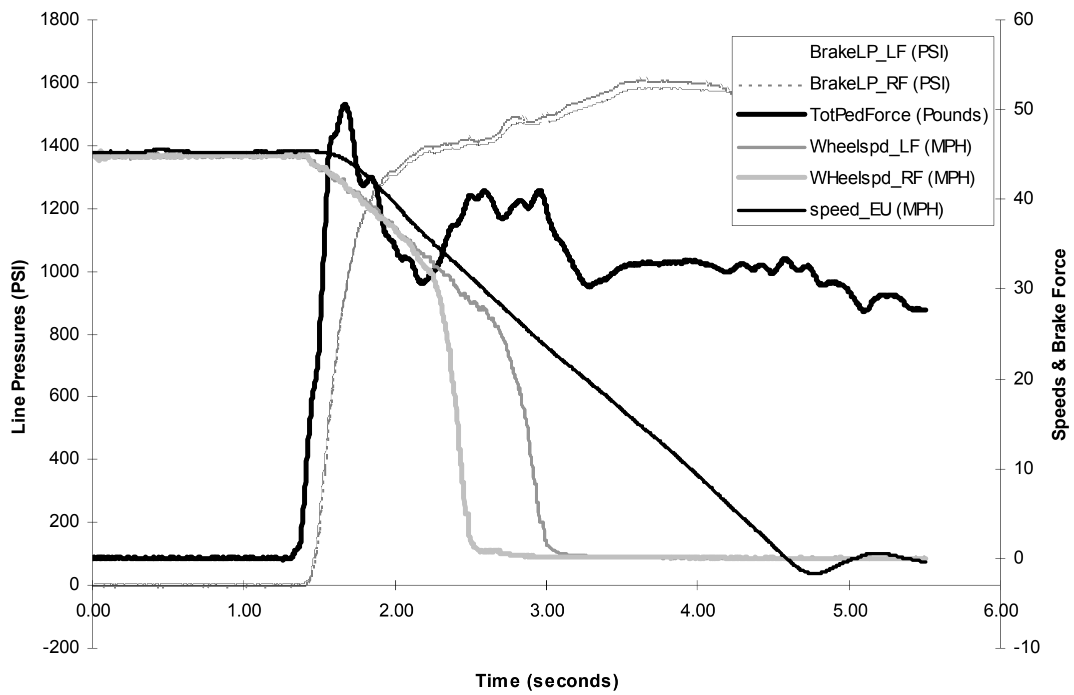

Figure 49. Measured applied brake pedal forces and associated brake line pressures during an avoidance maneuver in which the vehicle partially departed the roadway and wheel lockup with conventional brakes is believed to have occurred.

5.2.2. Partial Road Departure #2

Figure 50 depicts the response of a female subject in the dry pavement study who partially departed the road to the left after avoiding a collision with the incursion vehicle. She was driving the Ford Taurus configured with ABS under the 2.5 second TTI condition and received braking practice but no ABS instruction.

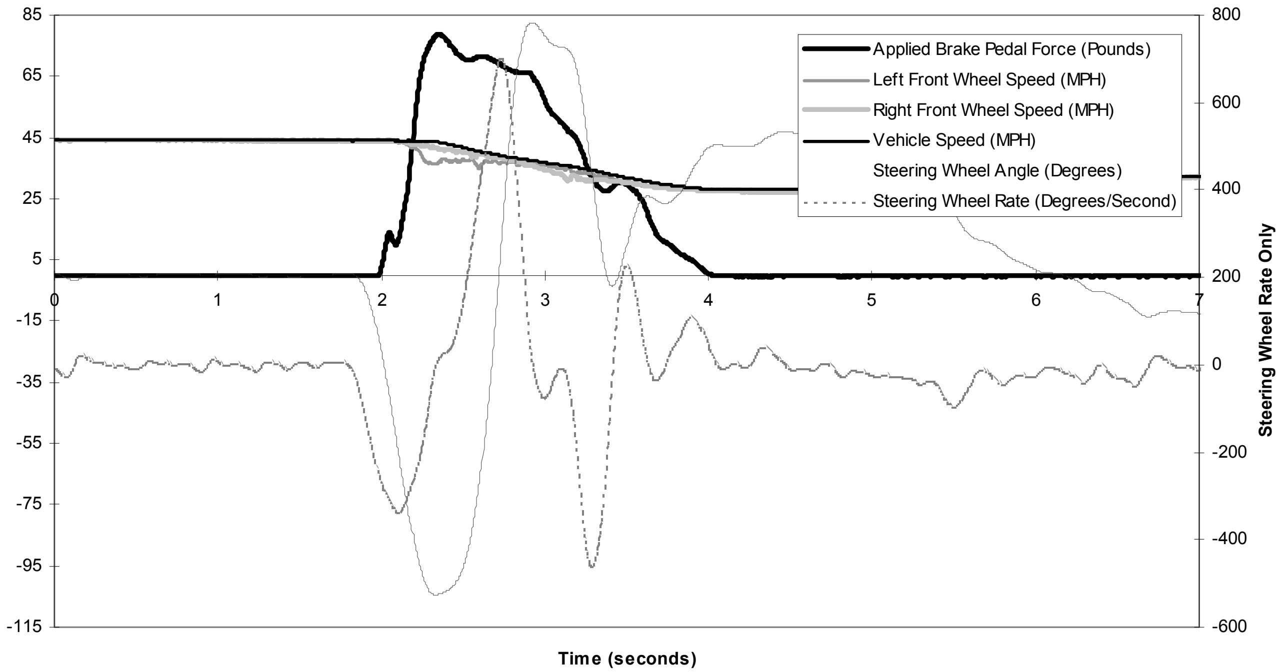

Figure 50. Illustration of the avoidance maneuver of a female subject that ended in a two-wheel, left side road departure with ABS on dry pavement.

She was traveling at 44 mph when the incursion vehicle began to move into the intersection. The initial reaction time observed was 1.91 seconds at which time she initiated a steering input of 104.5 degrees to the left and simultaneously released the throttle. At 1.98 seconds, the subject applied the brakes as can be seen in Figures 50 and 51. A maximum brake pedal force of 78.8 pounds was quickly reached and ABS was activated. At 2.35 seconds after the start of the incursion, the subject changed steering directions by making a first lane recovery steering input of 83 degrees to the right resulting in a first lane recovery input range of 187 degrees to the right. The subject successfully avoided a crash with the incursion vehicle but did experience a two-wheel road departure to the left prior to initiating a lane recovery steering input. At 3.90 seconds past the start of the incursion, the subject released the brake pedal signaling the end of the incursion event.

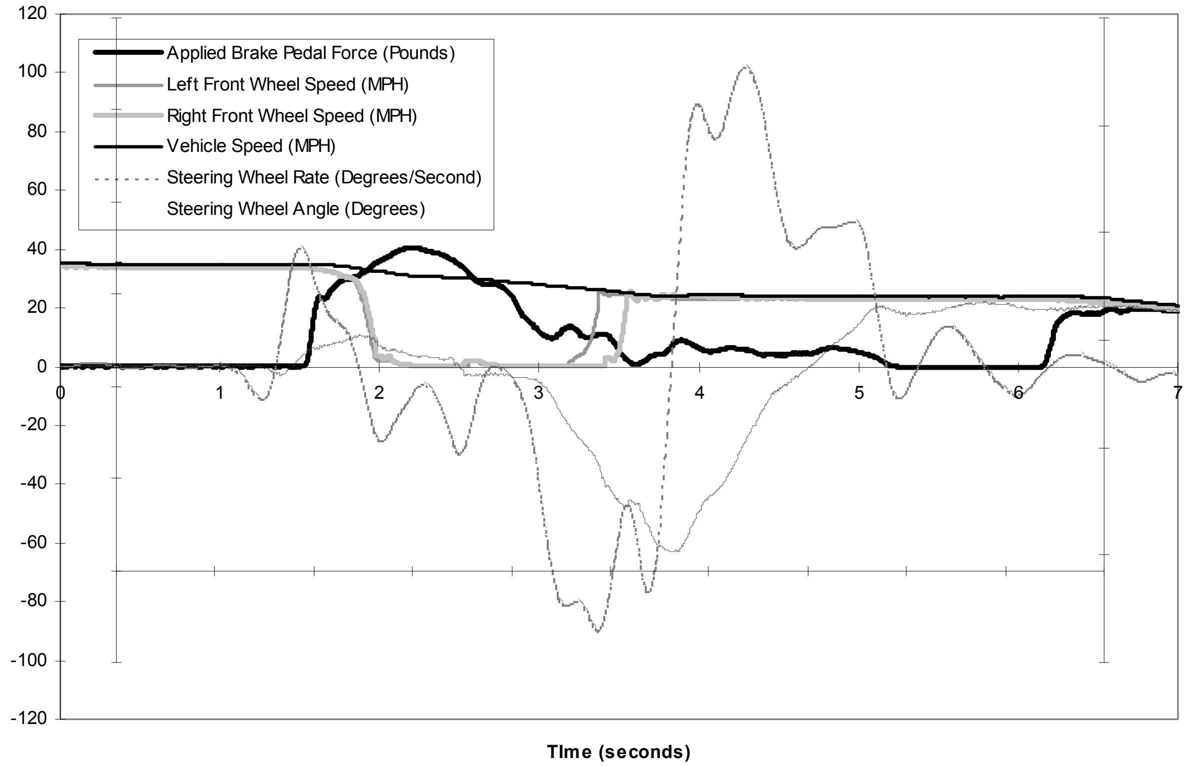

Figure 51. Measured applied brake pedal forces and associated brake line pressures during an avoidance maneuver in which the vehicle partially departed the roadway and ABS activation is believed to have occurred.

5.2.3. Partial Road Departure #3

Figures 52 and 53 depict the crash avoidance response of a female subject in the wet pavement study who partially departed the road to the right after hitting the rear of the incursion vehicle. The subject was driving the Ford Taurus test vehicle configured with conventional brakes when she experienced this one-wheel road departure to the right.

This female subject was driving at a speed of 35 mph when the incursion vehicle began to move into the intersection. Her initial reaction time was 1.28 seconds at which time she released the throttle. At 1.53 seconds after the start of the incursion, the subject applied the brakes. The subject's applied brake pedal force reached a quick maximum of 41 pounds during the beginning of the crash avoidance maneuver. She began a steering input of 11 degrees to the right at 1.58 seconds past the start of the incursion. As illustrated in Figure 53, all four wheels of the vehicle were basically locked for a period of 1.5 seconds beginning approximately 2 seconds after the start of the incursion. The subject steered relatively little and thus, basically drove straight and collided with the front half of the incursion vehicle which covered the right half of her travel lane. Beginning at approximately 2.15 seconds after the start of the incursion, the subject gradually reduced the applied brake pedal force. The applied brake pedal force had been reduced enough by the 3.50 second mark to allow both front wheels to unlock.

Figure 52. Illustration of the avoidance maneuver of a female subject that ended in a one-wheel road departure with conventional brakes on wet pavement.

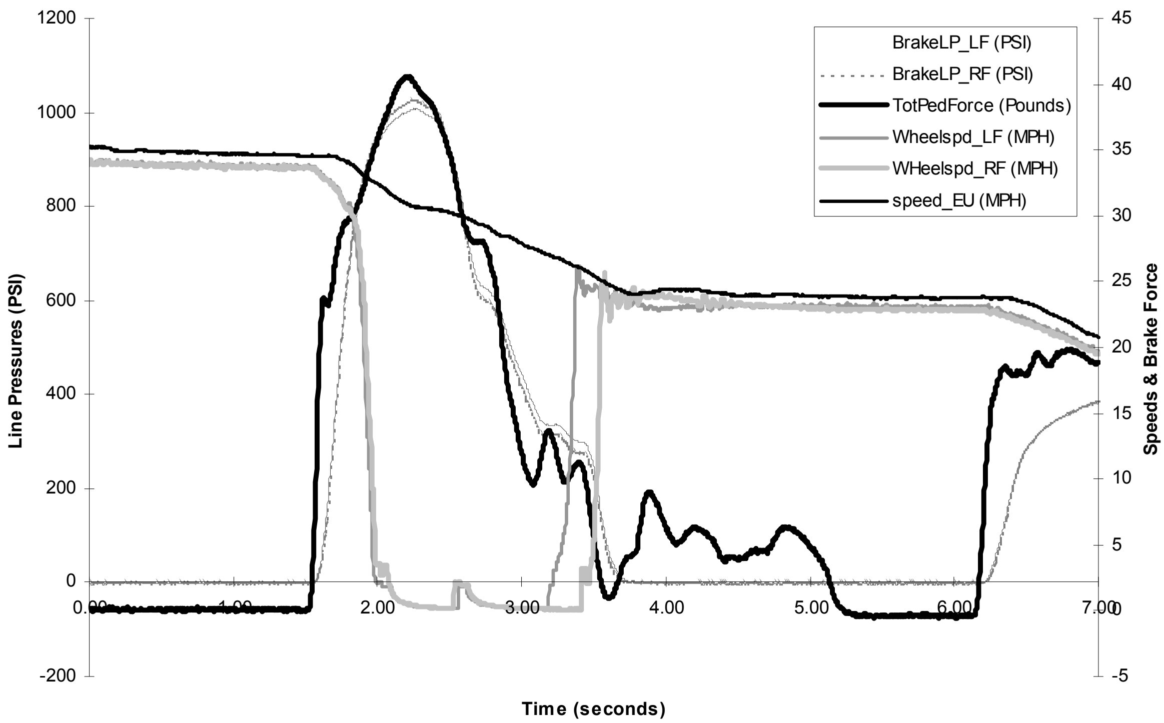

Figure 53. Measured applied brake pedal forces, wheel speeds, and associated brake line pressures during an avoidance maneuver in which the vehicle partially departed the roadway and wheel lockup with conventional brakes is believed to have occurred.

After colliding with the incursion vehicle, at 3.85 seconds after the start of the incursion, the subject changed steering directions by initiating a steering input of 74 degrees (range) to the left. This lane recovery steering input reached a maximum handwheel angle of 63 degrees and caused one wheel of the test vehicle to depart the right side of the roadway. Lastly, 3.84 seconds past the start of the incursion, the subject made a steering input of 85 degrees to the left to return the vehicle to its original lane of travel.

6.0 QUESTIONNAIRE RESULTS

Each subject filled out a questionnaire during a debriefing session that followed the driving participation. The purpose of the questionnaire was to gather information regarding driver demographics, driving habits, personal vehicle information, past driving experiences, driver behavior in response to the incursion scenario, and drivers' perceptions about the reality of the scenario. A copy of the actual questionnaire is located in Appendix J.

6.1. DRIVER DEMOGRAPHICS

Overall, 245 subjects participated in this research, 192 subjects in the dry pavement study and 53 subjects in the wet pavement study. The dry pavement study consisted of 104 males and 88 females while the wet pavement study consisted of 26 males and 27 females. They ranged in age from 25 to 55 with the average age being approximately 41 years.

6.1.1. Marital Status

Approximately 56 percent of the subjects were married in the dry pavement study while 64 percent were married in the wet pavement study.

6.1.2. Work

Over 59 percent of subjects in the dry pavement study were employed full-time while 53 percent of subjects in the wet pavement study were employed full-time (see Table 71). Note that a higher percentage of unemployed subjects were tested than might have been predicted based on the area's unemployment rate at that time (approximately 4 percent).

Table 71. EMPLOYMENT STATUS: Response Percentages.

Response	Overall	Dry	Wet
Full-Time	57	59	53
Part-Time	22	21	25
Unemployed	16	15	19
Retired	3	3	4
None	2	3	0

6.1.3. Education

At least 96 percent of the subjects had a high school diploma and about half of them had some form of higher education.

6.2. DRIVING HABITS AND EXPERIENCE

All of the subjects reported driving regularly, except for three who did not respond to the question (however, only people who reported driving at least 3000 miles per year were eligible for participation in this testing). Ninety-seven percent of the subjects who responded to this question in the dry pavement study reported driving at least once daily and the other 3 percent reported driving at least once weekly. Ninety-eight percent of the responding subjects in the wet pavement study reported driving at least once daily and the other 2 percent reported driving at least once weekly. About half of the subjects drove over 13,000 miles per year (see Table 72).

Table 72. DRIVING EXPERIENCE: Response Percentages.

QUESTION	Response	Overall	Dry	Wet
Miles Driven Per Year	0 – 2,000	2	3	2
	2,000 – 8,000	17	17	17
	8,000 – 13,000	30	34	17
	13,000 – 20,000	30	29	36
	20,000 or more	20	18	28
Work Miles Driven Per Year	0 – 2,000	27	26	32
	2,000 – 8,000	29	31	23
	8,000 – 13,000	16	12	32
	13,000 – 20,000	5	7	0
	20,000 or more	22	24	14
Typical Driving Environment	Rural Highway	37	36	42
	Small Town	20	19	26
	Suburban	8	8	8
	City	28	31	15
	High Density City	2	2	4
	Highway / Freeway	25	27	19

6.2.1. Work-Related Driving

Forty-seven percent (dry) and 42 percent (wet) of the subjects performed work-related driving. In the dry pavement study, 7 percent of subjects were truck drivers and another 2 percent were bus drivers. Three percent of the dry pavement study subjects were driver's education teachers and one person was an armored car driver, one was a valet, and one was a tow truck driver. In the wet pavement study, only 2 percent were truck drivers and another 2 percent were into some sort of automotive transport occupation. Most of the subjects who did work-related driving did not specify the type of driving task. Nearly one-fourth of the work-related drivers claimed to drive over 20,000 miles per year at work.

6.2.2. Training

Twenty-six drivers reported having participated in some sort of special driving school. When asked how they first learned to drive, 96 subjects said they learned through formal instruction such as a driver's education class. Sixty-three subjects learned informally from a friend or relative. Eighty-four subjects reported learning to drive through a combination of both formal and informal instruction. Two subjects did not respond to the question.

6.2.3. Experience

Approximately one-third of the drivers typically drive on rural highways and another one-third typically drive in the city for the dry pavement study while the wet pavement study had somewhat different percentages. In general, all subjects appeared to be experienced drivers. This was to be expected given the sample population age range of 25 to 55. Therefore, there is no indication that a lack of driving experience had any influence on the study results.

6.3. DRIVER BEHAVIOR

Questions were asked to try and obtain subjects' personal judgments about their behaviors and comfort levels during a variety of situations or conditions. Discussions of these questions are provided in the following sub-sections. A summary of responses to questions dealing with driver behavior is provided in Tables 73 and 74.

6.3.1. What speed do you typically drive at when the posted speed limit on a road is: 35, 45, 55, 65?

In any of the four speed limit categories in either study, less than 13 percent of the subjects would drive below the posted speed limit. For each of the four speeds queried, most people reported a tendency to drive at or above the speed limit. Few subjects, however, reported going more than 5 to 10 miles per hour over any of the posted speed limits.

6.3.2. How comfortable do you feel when you drive in the following conditions or perform the following maneuvers?

In the questionnaire, subjects were asked to rate their comfort level during various driving circumstances. There were four levels of response ranging from very comfortable to very uncomfortable. "Not applicable" was also an option, aside from the four levels. Many questions were not designed to provide information relative to this particular study but rather to provide information about the subjects' personal driving behaviors. In the figures to follow: VC = very comfortable, SC = slightly comfortable, SU = slightly uncomfortable, VU = very uncomfortable, and NA = not applicable.

As far as environmental conditions were concerned, snow and fog were equivalently reported to be the most uncomfortable driving conditions. For snow, 51 percent of the dry pavement subjects were slightly uncomfortable and 12 percent were very uncomfortable while the wet pavement subjects had similar responses with 58 percent reporting slight discomfort and 4 percent responding, "very uncomfortable". For fog, 48 percent of subjects in the dry pavement study were slightly uncomfortable and 12 percent were very uncomfortable while, in the wet pavement study, 53 percent were slightly uncomfortable and 4 percent were very uncomfortable. Nighttime was the most comfortable condition, and rain also appeared to be a fairly comfortable condition, however, a few subjects were still very uncomfortable with these conditions.

For road scenarios, at least 90 percent of the subjects were slightly comfortable with driving on the highway. Driving during rush hour and in high density traffic seemed to evoke similar levels of comfort. Each had nearly 50 percent being at least slightly comfortable and 50 percent being uncomfortable. About three-fourths of the subjects were comfortable with passing other cars and with making left turns at uncontrolled intersections. Nearly 90 percent of the subjects were comfortable with changing lanes.

For in-vehicle conditions, over 80 percent of the subjects were comfortable driving with children in the car. Another 10 percent reported never driving with children and deemed the question not applicable. Approximately 36 percent of the subjects were smokers and reported they normally smoke while driving. Approximately one-third of the subjects were comfortable with smoking in the car while driving. Two percent of subjects in the wet pavement study and five percent of the subjects in the dry pavement study reported being at least slightly comfortable with driving after drinking alcohol. Three-fourths of the subjects felt that the alcohol question was not applicable, i.e., they do not drive after drinking.

Table 73. DRIVING BEHAVIOR: Response Percentages.

QUESTION	Response	Overall	Dry	Wet
Typical Speed Driven When the Posted Speed Limit is 35 mph	Below 35	4	4	4
	35 mph Limit	49	48	53
	Above 35	46	47	43
Typical Speed Driven When the Posted Speed Limit is 45 mph	Below 45	5	5	4
	45 mph Limit	48	45	57
	Above 45	48	50	40
Typical Speed Driven When the Posted Speed Limit is 55 mph	Below 55	3	4	0
	55 mph Limit	26	24	32
	Above 55	71	72	68
Typical Speed Driven When the Posted Speed Limit is 65 mph	Below 65	9	8	11
	65 mph Limit	36	35	38
	Above 65	55	57	51
Comfort Level at Night	Very Comfortable	54	54	53
	Somewhat Comfortable	24	27	17
	Somewhat Uncomfortable	18	16	25
	Very Uncomfortable	3	3	6
	NA	0	1	0
Comfort Level in Fog	Very Comfortable	7	7	6
	Somewhat Comfortable	34	33	38
	Somewhat Uncomfortable	49	48	53
	Very Uncomfortable	10	12	4
	NA	0	0	0
Comfort Level in Rain	Very Comfortable	25	26	25
	Somewhat Comfortable	40	40	42
	Somewhat Uncomfortable	31	31	32
	Very Uncomfortable	3	4	0
	NA	0	0	2
Comfort Level in Snow or Sleet	Very Comfortable	11	11	8
	Somewhat Comfortable	26	24	30
	Somewhat Uncomfortable	53	51	58
	Very Uncomfortable	10	12	4
	NA	1	1	0
Comfort Level During Rush Hour	Very Comfortable	23	23	25
	Somewhat Comfortable	29	32	19
	Somewhat Uncomfortable	36	35	40
	Very Uncomfortable	10	9	13
	NA	2	1	4

Table 74. DRIVING BEHAVIOR: Response Percentages (Continued).

QUESTION	Response	Overall	Dry	Wet
Comfort Level on Highway / Freeway	Very Comfortable	74	74	75
	Somewhat Comfortable	16	16	15
	Somewhat Uncomfortable	5	4	8
	Very Uncomfortable	3	4	0
	NA	2	2	2
Comfort Level While Smoking	Very Comfortable	27	27	28
	Somewhat Comfortable	5	6	2
	Somewhat Uncomfortable	1	2	0
	Very Uncomfortable	2	2	2
	NA	65	64	68
Comfort Level After Drinking Alcohol	Very Comfortable	1	1	0
	Somewhat Comfortable	3	4	2
	Somewhat Uncomfortable	8	9	4
	Very Uncomfortable	14	14	15
	NA	74	72	79
Comfort Level With Children	Very Comfortable	60	59	62
	Somewhat Comfortable	22	23	21
	Somewhat Uncomfortable	4	4	2
	Very Uncomfortable	3	3	2
	NA	11	10	13
Comfort Level in High Density Traffic	Very Comfortable	25	26	23
	Somewhat Comfortable	33	32	36
	Somewhat Uncomfortable	35	35	34
	Very Uncomfortable	7	7	8
	NA	0	1	0
Comfort Level When Passing Other Cars	Very Comfortable	43	41	51
	Somewhat Comfortable	31	32	28
	Somewhat Uncomfortable	22	22	19
	Very Uncomfortable	3	4	2
	NA	0	1	0
Comfort Level When Changing Lanes	Very Comfortable	56	56	57
	Somewhat Comfortable	33	34	32
	Somewhat Uncomfortable	9	8	11
	Very Uncomfortable	2	2	0
	NA	0	0	0
Comfort Level When Making Left Turns at Uncontrolled Intersections	Very Comfortable	44	41	55
	Somewhat Comfortable	33	35	25
	Somewhat Uncomfortable	19	19	19
	Very Uncomfortable	4	5	2
	NA	0	0	0

6.4. VEHICLE INFORMATION

6.4.1. Which of the following features does your current automobile have?

This question was used to assess what type of features were on the subjects' current vehicles such as air bags, antilock brakes, an automatic or manual transmission, CB radio, cellular phone, power steering, radar detector, and others. Subject recruitment attempts focused on finding subjects who did not have four-wheel ABS on their primary vehicle. However, approximately 20 percent stated they had ABS on their primary vehicle in this question. It is not sure whether they had four-wheel ABS, two-wheel ABS, or just answered wrong (see section 6.7 for driver knowledge of ABS or lack there of). Results for other features are shown in Table 75

Table 75. VEHICLE INFORMATION: Response Percentages.

QUESTION	Response	Overall	Dry	Wet
Reported Vehicle Features	ABS	21	19	26
	Airbag	24	23	26
	Automatic	73	72	77
	Manual	27	28	23
	Phone	10	8	17
	Power Brakes	85	84	89
	Power Steering	87	86	89
	Radar Detector	6	6	6

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6.4.2. How many vehicles have you driven on a regular basis over the last 5 years?

In the dry pavement study, 28 percent of the subjects had driven five or more vehicles regularly within the past five years while 23 percent of the wet pavement study subjects had driven five or more vehicles. Another 39 percent and 47 percent of subjects from the dry and wet pavement studies respectively had driven three to four cars in the last five years. Based on this information, it seems a majority of the subjects drove multiple vehicles or purchased new or pre-owned vehicles relatively frequently.

6.4.3. Do you personally do the maintenance on your vehicles?

Drivers were also asked a few questions pertaining to their past vehicle experiences and to gain insight regarding their knowledge about cars. Subjects who worked on their own cars might be considered to be more likely to have greater knowledge of automotive brake systems. Forty-two percent of the subjects in the dry pavement study stated that they did at least some of their own vehicle maintenance (which included oil changes, tire changes, etc.) while 51 percent of the wet pavement study subjects admitted to having done some maintenance themselves.

6.5. PAST BRAKING EXPERIENCES

In order to assess drivers' experiences in severe braking, loss of control, or road departure situations in the past, three questions were asked which pertained to brakes, brake lockup, and run-off-road situations.

6.5.1. "Regardless of what road you were on, have you ever had to brake your vehicle so sharply that your brakes locked and you went into a skid (If so, describe the road, vehicle, speed, and environmental conditions at the time)?"(Question 22)

Approximately 30 percent of the subjects in the dry pavement study reported no conditions in which their brakes have ever been locked and resulted in a skid. In the wet pavement study, 32 percent of the subjects reported never having their brakes lock and result in a skid. Another 39 percent of subjects in the dry pavement study reported a lockup with a skid occurring during adverse weather conditions such as rain or snow while 34 percent of subjects in the wet pavement study reported such an incident. See Table 76 for more details based on environmental conditions.

6.5.2. "Describe any other instances where you may have had a braking problem, a run-off-the-road problem, or any problem which may have occurred as a result of trying to stop your vehicle abruptly" (Question 23)

Approximately 40 percent of the subjects reported having some sort of other braking problem in their past experiences.

6.5.3. "If you have ever driven off the road to avoid a collision, please describe the situation including your reasoning behind the decision to drive off road" (Question 24)

Thirty-five percent of the subjects in the dry pavement study reported having to drive off the road to avoid a collision at least once in their life. In the wet pavement study, 31 percent of the subjects reported having to drive off the road to avoid a collision at least once in their life. Most of these road departures were due to either cars, or animals (such as deer and dogs) coming out in front of the vehicle's path when the roads were dry, instead of bad weather causes such as snow or rain. See Table 76 for more information.

Table 76. PAST BRAKING / OFF ROAD EXPERIENCES: Response Percentages.

QUESTION	Response	Overall	Dry	Wet
Locked Brakes and Went into a Skid	Dry / Not Specific	28	28	29
	Wet / Rain	14	14	12
	Ice / Snow	24	25	22
	None	30	30	32
	No Response	4	4	4
	Fog	0	0	2
Other Braking Problem	Dry / Not Specific	19	19	20
	Wet / Rain	3	3	4
	Ice / Snow	15	16	15
	None	33	34	26
	No Response	30	29	34
Off Road Conditions	Dry / Not Specific	28	29	25
	Wet / Rain	2	2	2
	Ice / Snow	4	4	4
	None	42	43	38
	No Response	24	22	32

6.6. RESPONSES TO QUESTIONS REGARDING THE INCURSION SCENARIO

6.6.1. "What do you think the purpose of today's drive was?" (Question 1)

The purpose of this question was to see if, after completing the incursion scenario, subjects realized the study was about ABS. When asked what the purpose of the drive was, 43 percent of subjects in the dry pavement study and 58 percent of subjects in the wet pavement study thought the study was to test driver response, reaction, or reaction time. Only 18 percent of subjects in the dry pavement study and 11 percent of subjects in the wet pavement study stated that it was a brake test, with about half of that percentage mentioning ABS. Other purposes listed included such responses as driver safety, accident prevention, information gathering, handling the unexpected or crisis situation, study driving habits and maneuverability, collect data on maintaining speed and distance, reflexes testing, driver awareness, and several other combinations of answers covering the above concepts.

6.6.2. "At any point during the driving task did you begin to drive more carefully than you normally would in typical daily driving?" (Question 2)

This question was used to see if subjects felt they drove differently than normal during the test. Approximately 38 percent of the subjects in the dry pavement study and 60 percent of the subjects in the wet pavement study reported driving more carefully than they normally drive. A few subjects claimed this change in behavior was due to the feeling of being tested. Others attributed the carefulness to being in a new area and environment, not previously explored. Some attributed it to having to maintain a certain speed or distance during the drive. A large number of subjects noted they did not start driving more carefully until after the intersection incursion event was over. This change in behavior after the incursion event is irrelevant to test results since all research data was collected prior to and during the incursion event. As a result, the assumption can be made that they were driving as they normally would throughout the test. Factoring in this assumption would somewhat alter the percentage of those who drove more carefully (with approximately 31 percent claiming to be driving more carefully in the dry pavement study and 28 percent claiming to be driving more carefully in the wet pavement study) than they would normally drive. This means that 69 percent and 72 percent of subjects, in the dry and wet pavement studies respectively, felt they drove "normally" until reaching the intersection incursion event.

6.6.3. "During the driving task, did you feel that the other vehicles you encountered behaved the way you would expect them to in a real world driving situation?" (Question 3)

The purpose of this question was to find out if subjects thought the behavior of the scenario vehicles was realistic. If subjects thought the scenario seemed realistic, then it is likely their response was genuine. The realism of the event was supported by the fact that 87 percent of the subjects in the dry pavement study and 87 percent of the subjects in the wet pavement study felt the other vehicles (e.g., scenario vehicles, lead car, and unrelated vehicles) on the test track behaved as expected.

6.6.4. "Remember when you approached the intersection and the vehicle pulled out in front of you? Did this sequence of events seem realistic?" (Question 4)

This question had the same purpose as the previous question, to re-affirm the realism of the scenario. The realism of the event was also supported by the fact that 91 percent of the subjects in the dry pavement study and 94 percent of the subjects in the wet pavement study said the incursion scenario's sequence of events did seem realistic to them.

6.6.5. "When you approached the intersection, did you anticipate or expect that the car might pull out in front of you?" (Question 5)

The purpose of this question was to assess whether there was any anticipation of the incursion event. Thirty-one percent of the subjects in the dry pavement study and 23 percent of the subjects in the wet pavement study stated they anticipated or expected the car might pull out in front of them. The reasoning given by most of them was they always expect the other vehicle to pull out because it happens so often in the real world (defensive driving), not because they knew about the test, had figured it out ahead of time, or were uneasy about the drive.

6.6.6. "When you approached the vehicles at the intersection, did you react to them in the same manner as you would react to vehicles in a similar scenario in a real world driving situation?" (Question 6)

The purpose of this question was to see if the scenario elicited a genuine crash avoidance response from subjects. A majority of the subjects tested, 79 percent in the dry pavement study and 81 percent in the wet pavement study, thought their reaction was as it would have been in a real world driving situation involving similar circumstances.

6.6.7. "Did you think that the vehicle which pulled out in front of you was: a) real car, same one the whole time, b) real car, but different than previous laps, c) a fake car, or d) other?" (Question 7)

The purpose of this question was to determine whether subjects realized the incursion vehicle was not a real car. When given a list of choices for identification of the incursion vehicle, about 45 percent of the subjects in the dry pavement study and 63 percent of the subjects in the wet pavement study thought it was a real car. Forty-eight percent of subjects in the dry pavement study and 30 percent of the subjects in the wet pavement study thought it was a fake car. The remaining subjects thought the car was real, but not the same vehicle that had been positioned in that location on previous laps.

6.6.8. "If you realized that the car was fake, at what point did you realize it was fake: a) visual spot, b) started to pull out, c) not until I hit it, d) not until drove around it, or e) other?" (Question 8)

Of those who stated the incursion vehicle was fake, 33 percent of the subjects in the dry pavement study and 18 percent of the subjects in the wet pavement study did not notice it was fake until the incursion motion began. Approximately 22 percent of the subjects in the dry pavement study and 53 percent of the subjects in the wet pavement study did not realize it was fake until they either collided with it or drove around it. Many subjects verbally reported that even though they knew it was not a real car, they still did not want to hit it and cause damage to the test vehicle.

6.6.9. "Did anything about the vehicle which pulled out in front of you seem strange or unrealistic? (Please explain.)" (Question 9)

The purpose of this question was to see which characteristics of the incursion vehicle were most likely to be perceived by subjects as indications that the vehicle was not a real car. About half of the subjects in each study reported that something about the incursion vehicle seemed strange or unrealistic. Some reported the color of the vehicle looked peculiar, while others noticed a lack of dimensionality. A few people even noticed the wheels were not moving on the incursion vehicle.

6.6.10. "Were you startled by the vehicle pulling out in front of you?" (Question 10)

Whether they knew the incursion vehicle was fake or not, 88 percent of the subjects in the dry pavement study and 94 percent of the subjects in the wet pavement study claimed they were startled by the vehicle pulling out into the intersection. The fact that subjects were surprised by the incursion event indicates that subjects' crash avoidance responses were genuine and likely to be similar to those they would exhibit in a similar real-world situation.

6.6.11. "Why did you react the way you did when the vehicle pulled out in front of you?" (Question 12)

When subjects were asked why they reacted in the manner they did in response to the incursion, whether it was braking, steering, or another response, 21 percent of the subjects in the dry pavement study and 22 percent of the subjects in the wet pavement study reported it was due to a natural reaction or instinct. Sixty-seven percent of the subjects in the dry pavement study and 61 percent of the subjects in the wet pavement study stated they reacted out of fear or an overwhelming desire to avoid a collision. Only 7 percent of the subjects in the dry pavement study and 9 percent of the subjects in the wet pavement study thought that training or experience was the cause of their response. Five percent of the subjects in the dry pavement study and 7 percent of the subjects in the wet pavement study did not know why they responded the way they did.

6.6.12. "At any time when the vehicle was pulling out in front of you, did you notice where the driver of that car was looking?" (Question 13)

In an effort to gauge the level of attention subjects were paying to the scenario vehicles positioned at the intersection, they were asked where they thought the person in the incursion vehicle was looking. If subjects thought the driver was looking straight ahead, they might assume the incursion vehicle would continue through the intersection without stopping. Approximately 87 percent of the subjects in the dry pavement study and 83 percent of the subjects in the wet pavement study did not notice which way the driver of the incursion vehicle was looking. Another 2 percent in the dry pavement study stated they knew which way the driver was looking but then 'guessed' wrong when stating which direction the driver of the incursion vehicle was looking. Therefore, approximately 11 percent of the subjects in the dry pavement study and 17 percent of the subjects in the wet pavement study thought they knew which way the driver was looking, and were correct.

6.6.13. "Did you notice whether or not the driver of that car was the same person that was in the car located there previously?" (Question 14)

Subjects were asked whether they noticed that the driver in the real vehicle was the same person as the one pictured on the foam incursion vehicle. If subjects realized that the driver of the vehicle at the right side of the intersection had changed, this might indicate that they could be suspicious of what might occur at the intersection. Seventy-nine percent of the subjects in the dry pavement study and 83 percent of the subjects in the wet pavement study did not know if the driver was the same as the one there on previous passes through the intersection.

6.6.14. "When you tried to avoid hitting the car, do you feel that you reacted as you would have during a real world situation as opposed to our test track environment?" (Question 15)

The purpose of this question was to gain the subjects' retrospective perceptions of the genuineness of their responses. Upon reflecting back at their reaction, 84 percent of the subjects in the dry pavement study and 81 percent of the subjects in the wet pavement study thought they would have reacted in the same manner to avoid a crash as if it had happened in the real world.

6.6.15. "If the situation where the vehicle pulled out from the intersection had occurred in the real world, what would you have done?" (Question 21)

A series of maneuver choices were given as potential responses to this question. When asked what they would have done in the real world, if such an event occurred, 58 percent of the subjects in the dry pavement study and 45 percent of the subjects in the wet pavement study would brake and steer left. This maneuver was the choice by a majority of subjects. Only 18 percent and 19 percent would just brake without steering in the dry pavement and wet pavement studies, respectively. Eleven percent of the subjects in the dry pavement study and 4 percent of subjects in the wet pavement study would respond without using their brakes by just steering, and in some cases, accelerating along with steering.

6.7. QUESTIONS REGARDING DRIVER KNOWLEDGE OF ABS

Subjects were asked a series of ABS-specific questions to gain insight into the population's knowledge about ABS.

6.7.1. "Do you know what the initials "ABS" stand for?" (Question 17)

Only 63 percent of the subjects in the dry pavement study and 64 percent of the subjects in the wet pavement study actually knew what the initials ABS stood for. Overall, thirty-four percent of subjects received video instruction that clearly stated the meaning of the initials "ABS" prior to answering this question. The 63 percent (dry) and 64 percent (wet) figures could have been much lower if ABS instruction had not been provided. Nineteen percent of the subjects in the dry pavement study and 23 percent of the subjects in the wet pavement study thought ABS stood for something else like "Air Bag System" or "Automatic Braking System".

6.7.2. "If you braked to try to avoid hitting the car which pulled into the intersection in front of you, did you activate the ABS system while braking?" (Question 18b)

Subjects were asked whether or not they activated ABS during the incursion event. A majority of them stated it was not activated. However, many probably did not know what to look for to see if it was activated since only 63 percent (dry) and 64 (wet) percent knew what the initials, "ABS", meant.

6.7.3. "Have you ever activated an antilock brake system in ANY vehicle you have ever driven?" (Question 19)

Subjects were then asked if they had ever activated an antilock brake system before in any vehicle. Twenty-two percent of the subjects in the dry pavement study and 30 percent of the subjects in the wet pavement study stated having tried an antilock brake system before, many of which tried it in a parking lot in a car they did not own, such as a rental car or friend's vehicle.

6.7.4. "In your opinion, does an antilock brake equipped vehicle provide an advantage over conventional braking during a similar situation (when a vehicle pulls out in front of you) in the real world?" (Question 20)

Sixty-three percent of the subjects in the dry pavement study and 70 percent of the subjects in the wet pavement study believed an ABS-equipped vehicle had an advantage over a conventional braking system during such a situation as the incursion event. Only three percent of the subjects in the dry pavement study and eight percent of subjects in the wet pavement study saw ABS as a disadvantage. Thirteen percent of the subjects in the dry pavement study and 4 percent of the subjects in the wet pavement study felt the ABS and conventional braking systems were equally capable in such a situation, thus no ABS advantage. Approximately 21 percent of the subjects in the dry pavement study and 19 percent of subjects in the wet pavement study either did not know or had no opinion on the topic of ABS being an advantage or disadvantage.

The responses to the ABS specific questions support the existing notions that promote a need for widespread ABS education and training programs as a means of ensuring ABS success as a vehicular safety feature.

7.0 DISCUSSION

7.1. REALISM OF THE SCENARIO

Overall, approximately 87 percent of subjects in this research reported that they felt the vehicles involved in the incursion scenario behaved as vehicles do normally in real-world driving situations. Over 90 percent of subjects in both the dry and wet pavement studies stated that the incursion scenario's sequence of events seemed realistic to them. Only 31 percent of subjects in the dry pavement study and 24 percent of subjects in the wet pavement study recalled anticipating that the incursion vehicle might pull out in front of them. Approximately 52 percent of subjects in the dry pavement study and 69 percent of subjects in the wet pavement testing thought that the incursion vehicle was a real car. Despite whether subjects felt that the incursion vehicle was a real car, 88 percent of subjects in the dry pavement study and 94 percent of subjects in the wet pavement study claimed that they were startled by the vehicle pulling out in front of them. Overall, more than 80 percent of subjects reported that their response to the vehicle incursion was the same as that they would have exhibited if this had happened to them on the road. All of these factors combined suggest a high likelihood that the incursion scenario used in this research elicited a genuine crash avoidance response from subjects which can be used to make inferences about real world behavior.

7.2. RESEARCH QUESTIONS

7.2.1. Do drivers tend to both brake and steer in crash-imminent situations?

Steering while the vehicle's wheels are locked is basically ineffective in affecting the direction of travel of the vehicle. However, steering while ABS is activated does affect the path of the vehicle. If a driver steers excessively during an obstacle avoidance maneuver, the driver may unintentionally drive the vehicle off road. In this research, nearly all subjects in these studies both braked and steered in an attempt to avoid colliding with the incursion vehicle. Ninety-four percent of the subjects in the dry pavement study both braked and steered during their avoidance maneuver versus 98 percent in the wet test track study.

7.2.2. Do people exhibit excessive steering behavior during crash avoidance maneuvers?

In general, steering inputs exhibited by subjects in these test track studies were smaller and slower than those observed in the related IDS study [7,8,9]. This difference is believed to be attributable to the lack of "road feel" present on the IDS as well as the limited range of travel of the simulator motion base. However, the observed magnitudes and rates of steering inputs for these test track studies were still relatively large.

Observed steering rates varied by pavement condition and brake system, but overall were found to be impressively high. The mean maximum steering rates observed were 262 degrees per second on dry pavement versus 294 degrees per second on wet pavement. The highest steering rates observed in the dry test track study were 1159 degrees per second for ABS versus 982 degrees per second for the conventional brake system condition. In the wet test track study, the highest overall observed steering rate was yet higher at 1335 degrees per second for the ABS condition versus only 643 degrees per second for the conventional condition. Overall, ninety-five percent of the maximum steering rates were less than 597 degrees per second and 643 degrees per second in the dry and wet test track studies, respectively. Examining these data according to brake system, 95 percent of the steering rates were less than 584 degrees per second (dry) and 714 degrees per second (wet) for subjects in the ABS condition versus 703 degrees per second (dry) and 513 degrees per second (wet) for conventional brake system subjects.

Mean avoidance steering input magnitudes did not vary significantly by brake system for dry pavement. This is likely to be largely attributable to the fact that since only about 30 percent of subjects either locked wheels or activated ABS on dry pavement, functional ability to control the vehicle was not very different between the brake system condition levels. However, in the wet test track study in which nearly every subject either activated ABS or locked conventional brakes, the difference in mean magnitudes of avoidance steering inputs was statistically significant ($p = 0.0095$). Mean maximum steering input values also differed significantly ($p = 0.0058$) as a function of brake system for wet pavement wherein inputs for subjects with conventional brakes were much larger than for those with ABS. Thus, it is possible that during hard braking, subjects recognized the steering control afforded by ABS and therefore made smaller steering inputs than those made by subjects with conventional brakes.

Comparing steering input magnitudes for conventional brake system subjects who locked wheels versus those who did not lock wheels, some significant differences were found. On dry pavement, mean avoidance steering input magnitude was found to be significantly larger ($p = 0.0010$) for subjects who locked wheels with conventional brakes than for those who did not lock wheels. Also on dry pavement, mean maximum steering input magnitude for those who locked wheels in the conventional brake system case was significantly larger ($p = 0.0002$) than for those who did not lock wheels. Significant differences were not found for either steering magnitude measure as a function of activation for ABS on either pavement. This suggests that in cases in which vehicle control is compromised, drivers will steer more aggressively in order to try to affect the motion of the vehicle.

7.2.3. Do people utilize their brakes effectively during a crash avoidance scenario?

All but one subject applied the brakes at some point during their crash avoidance maneuver. Mean maximum brake pedal force values were 64 pounds and 68 pounds on dry and wet pavement, respectively. No significant differences were found for brake pedal force when brake systems were compared for either pavement condition.

Observed rates of ABS activation were 32 percent for dry pavement and 97 percent for wet pavement. The two vehicles used in this study were somewhat different in terms of their sensitivity to activation. The Chevrolet Lumina recorded ABS activations for brake pedal forces ranging from 13 to 240 pounds on wet pavement and 54 to 168 pounds on dry asphalt. Brake pedal forces resulting in ABS activation for the Ford Taurus ranged from 33 to 146 pounds for wet pavement and 51 to 188 pounds for dry asphalt. This difference in sensitivity amongst individual ABS models makes it difficult to generalize these results. However, since 97 percent of subjects successfully activated ABS on wet pavement it can be said that these subjects did use their brakes effectively.

Twenty-eight percent of subjects with conventional brakes experienced wheel lockup on dry pavement. These subjects who locked the vehicle's wheels crashed 15 percent more than those who did not lock the wheels. On wet pavement 94 percent of subjects in the conventional brake system condition experienced wheel lockup. However, all subjects with conventional brakes, regardless of whether or not they locked wheels, crashed on wet pavement. Although subjects in the conventional brake system condition may have used their brakes to the best extent possible, the obstacle avoidance scenario appears to have been severe enough that colliding with the incursion vehicle was unavoidable on wet pavement and very difficult on dry pavement.

7.2.4. Did people appear to use ABS correctly during this crash avoidance scenario?

Based on an examination of the video recordings of each subject's experience of the intersection incursion scenario from both the dry and wet pavement experiments, no evidence was observed of subjects either pulling their foot off of the brake pedal due to being startled by ABS pedal feedback, or attempting to "pump" the brake pedal with ABS. In addition, although a high number of instances of subjects "missing" the brake pedal on their first attempt at applying the brakes was seen, the number of instances observed did not show a significant difference due to brake system.

One might expect that subjects receiving ABS instruction might have longer brake pedal application durations as a result of being told not to "pump" the brake pedal with ABS. This was found to be true in the dry pavement study where subjects receiving ABS instruction had an average brake pedal application duration (2.46 seconds) which was significantly longer ($p = 0.0220$) than for those with ABS who received no instruction (1.93 seconds). However, in the wet pavement study in which 97 percent ABS activations were observed, subjects receiving ABS instruction had an average brake pedal application duration (2.09 seconds) which was similar to those with ABS who received no instruction (2.06 seconds).

7.2.5. Do people have more road departures in ABS-equipped vehicles than in conventionally braked vehicles?

Overall, results from this research indicate that, although subjects were observed making steering inputs characterized by large magnitudes and high rates, these aggressive steering inputs did not result in a significant number of road departures. ABS was not associated with a significantly higher number of road departures as compared to conventional brakes. Although the only two full road departures observed were associated with the ABS-enabled condition, neither could be directly attributed to ABS performance or driver interaction with ABS. In one case, activation occurred after the subject had steered off road. The other circumstance involved activation that occurred after a subject had begun a steering input to the right (heading off road) and was holding the steering wheel steady. Of the three partial road departures observed, two involved conventional brakes. The third partial road departure was not attributable to ABS since the ABS activation occurred at nearly the same time as the subject began a road recovery steering input.

The availability of detailed sensor data on driver inputs and vehicle motion is paramount in assessing whether or not ABS may contribute to a particular crash. Examination of crash database records and police accident reports rarely provide concrete information as to when the driver braked and steered, if at all, and whether ABS activation may have occurred. This test track research, although staged, provides as realistic and accurate information as is available regarding ABS involvement in road departure events relating to obstacle avoidance.

7.2.6. Do people crash less frequently in ABS-equipped vehicles than in vehicles equipped with conventional brakes?

On wet pavement, ABS was associated with significantly fewer crashes (42 percent less) than conventional brakes. However, no similar benefit was observed for dry pavement where a majority of subjects did not apply the brakes hard enough to activate ABS and or experience wheel lockup with conventional brakes. Overall, ABS was not associated with more crashes than conventional brakes for any factor discussed in this paper. In actuality, ABS was associated with slightly fewer crashes than conventional brakes for all factors discussed here. Tables 77 and 78 present crash percentages by the independent variables for the dry and wet test track studies, respectively. On wet pavement, twenty-eight percent fewer crashes were observed with ABS with heavy brake pedal feedback than with light feedback ABS, however, this result was not statistically significant. The degree of ABS pedal feedback present in a system did not seem to affect driver behavior in this type of situation.

Table 77. Summary of crash results by condition for dry pavement.

Condition	Dry – Percent Crashes
Overall	40
Conventional	45
ABS	38
ABS – Light Brake Pedal Feedback	33
ABS – Heavy Brake Pedal Feedback	42
ABS – No Instruction	36
ABS – Instruction	39
ABS – No Braking Practice	44
ABS – Braking Practice	31

Table 78. Summary of crash results by condition for wet pavement.

Condition	Wet – Percent Crashes
Overall	72
Conventional	100
ABS	58
ABS – Light Brake Pedal Feedback	72
ABS – Heavy Brake Pedal Feedback	44
ABS – No Instruction	50
ABS – Instruction	67
ABS – No Braking Practice	NA
ABS – Braking Practice	NA

The assumption can be made that in all cases in which subjects experienced wheel lockup with conventional brakes, if the vehicle had ABS, the ABS would likely have activated. Given this assumption, the potential benefit that could be obtained if ABS replaced conventional brakes in all cases in which wheel lockup was reached with conventional brakes can be calculated.

On wet pavement, 100 percent of subjects with conventional brakes who reached wheel lockup (94 percent of subjects with conventional brakes reached wheel lockup) crashed. Only 60 percent of subjects with ABS who activated ABS on wet pavement (97 percent of subjects with

ABS activated ABS on wet pavement) crashed. This suggests that ABS could have prevented up to 36 percent of the crashes observed with conventional brakes on wet pavement.

On dry pavement, 56 percent of subjects with conventional brakes who reached wheel lockup (28 percent of subjects with conventional brakes reached wheel lockup) crashed. Thirty-seven percent who activated ABS (32 percent of subjects with ABS activated ABS on dry pavement) crashed. Thus, on dry pavement, ABS could have prevented as much as 4 percent of crashes observed with conventional brakes on dry pavement. This benefit, although small, for dry pavement is interesting given that subjects with ABS crashed at approximately the same rate on dry pavement regardless of whether they activated ABS (37 percent) or not (38 percent) during their avoidance maneuver. In fact, 41 percent of subjects in the conventional brake system condition who did not experience wheel lockup during their avoidance maneuver crashed. Thus approximately the same outcome appears likely with ABS as can be obtained with conventional brakes on dry pavement as long as wheel lockup does not occur. This result appears to support the assumption that, at least for dry pavement, it is reasonable to expect unactivated ABS to perform similarly to conventional brakes when wheel lockup does not occur.

8.0 CONCLUSIONS

An experiment was conducted in which drivers' collision avoidance behavior in a simulated right-side intersection incursion scenario was examined as a function of vehicle brake system (conventional, ABS), pavement condition (dry, wet), braking practice, ABS instruction, and time-to-intersection (2.5, 3.0 seconds).

Results of this study found that nearly all subjects both braked and steered during their crash avoidance maneuvers. In fact, subjects in these studies demonstrated the capability to make aggressive steering and braking inputs. Some evidence of driver oversteering was seen. However, despite the high magnitudes and rates of many steering inputs observed, very few road departures occurred. Those road departures which were observed could not be judged attributable to ABS performance nor driver interaction with ABS. Although these data suggest that oversteering with ABS may not be responsible for the increase in single-vehicle road departure crashes, it is not clear whether the extent to which oversteering was seen in this study is comparable in proportion to that associated with the road departure crash trend phenomenon observed in conjunction with vehicles transitioning from conventional to antilock brakes.

ABS was found to have some beneficial effects on crash rates in this research. No significant reduction in crashes was seen on dry pavement for ABS versus conventional brakes regardless of training provided. ABS did not even become a factor in a majority of the dry pavement crashes since the activation/lockup percentage was only 31 percent. However, on wet pavement, where 97 percent of subjects activated ABS in the intersection incursion scenario, ABS was associated with significantly fewer crashes as compared to conventional brakes.

Even with no ABS instruction or braking practice, subjects with ABS crashed 50% less with ABS than with conventional brakes on wet pavement. Providing subjects with video instruction on the proper use of ABS did not produce a significant reduction in crashes for either pavement condition. For subjects in the dry pavement study who received braking practice prior to the incursion event, those with ABS crashed half as much as those with conventional brakes. Although providing ABS instruction did not reduce crashes in this research, there was evidence that ABS instruction may reinforce proper braking techniques.

Heavy ABS brake pedal feedback was associated with fewer crashes on wet pavement than was light ABS brake pedal feedback, however, not at a significant level. No evidence of subjects being startled by ABS brake pedal feedback and removing their foot from the brake pedal was seen in this research.

In conclusion, the results of this study do not appear to indicate that a problem exists due to driver crash avoidance behavior or driver interaction with ABS which would contribute to the apparent increase in fatal single-vehicle crashes as identified in conjunction with vehicles transitioning from conventional to antilock brake systems.

The authors acknowledge that these results are specific to the particular intersection incursion scenario used in this study and that the results may not apply to other types of crash avoidance scenarios. In addition, the authors believe that testing of this sort involving higher travel speeds (greater than 45 mph on dry and 35 mph on wet pavement) should be investigated. Additional insight may be obtained by conducting similar research using different crash avoidance scenarios and vehicle travel speeds. However, for the safety of human subjects, any higher speed testing would probably best be performed on a high-fidelity driving simulator.

In addition, these results leave some road departure related issues unaddressed. Due to the fact that steering and braking behavior after colliding with the incursion vehicle was not valid in terms of the incursion scenario, performance of subjects in recovering vehicle stability as well as road recovery behavior could not be fully assessed in this scenario for subjects who crashed. Also, the NASS CDS examination task of road departure crashes identified the phenomenon of a significant number of incidents in which multiple road departures occurred in a single crash event. This phenomenon could not be addressed in this research since road conditions (e.g., road edge drop-off, berm slope) and vehicle speeds conducive to the occurrence of multiple road departures could not be used for safety reasons.

Results from this study will also be examined in conjunction with the results of other tasks included in NHTSA's Light Vehicle ABS Research Program to determine whether the collective results viewed as a whole provide some insight into the cause of the increase in single-vehicle crashes observed in conjunction with the implementation of ABS.

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10.0 APPENDICES

10.1. APPENDIX A: SUBJECT RECRUITMENT NEWSPAPER ADVERTISEMENT

EARN $50 CASH

in about 90 Minutes !

L DRIVERS WANTED 7

Participate in a driving study at
Transportation Research Center
in East Liberty, Ohio
(60 miles NE of Beavercreek)

September - October
Appointment times vary
Weekdays & Saturdays
8 am - 7 pm

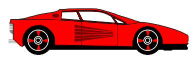
<u>MUST BE:</u>
Licensed driver
25-55 years old
Drive at least 3000 miles per year

If you would like to participate and meet these requirements,

PLEASE CALL JUDY at
1-800-262-8309
9 am - 6 pm weekdays

10.2. APPENDIX B: SUBJECT RECRUITMENT FLIER

$$ WANT $50 CASH FAST?? $$



Participate in a DRIVING STUDY
at Transportation Research Center (TRC)

in East Liberty!!

- ⇨ Takes about 90 minutes to participate
- ⇨ MUST be 25 - 55 years old
- ⇨ MUST drive at least 3,000 miles per year
- ⇨ MUST be in good health
- ⇨ Appointments open September - October

☎ Call Judy, weekdays 9 am - 5 pm,
1-800-262-8309

Driving Study, Judy
1-800-262-8309

Driving Study, Judy
1-800-262-8309

Driving Study, Judy
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Driving Study, Judy
1-800-262-8309

10.3. APPENDIX C**: INFORMATION SUMMARY AND INFORMED CONSENT FORM**

INFORMATION SUMMARY

Project Title: Normal Driver Data Collection
Principal Investigators: Liz Mazzae

Background: Thank you for coming in today. We are interested in having you participate in an effort to collect data on how people drive. We are interested in learning about things such as how well average people are able to maintain a vehicle's position within the lane while driving down the road and other aspects of the manner in which average people drive. Your assistance will help the United States Government's National Highway Traffic Safety Administration (NHTSA) understand the relationship between driver behavior and automotive safety. If you agree to participate, you will be asked to sign an Informed Consent Form indicating that you have read and understand the procedures of this study.

Study Description: You will also be asked to answer some initial questions, drive for approximately 30 minutes (as directed by an in-vehicle experimenter), and then complete a questionnaire asking your opinions regarding driving automobiles and your experience in today's data collection effort.

Compensation: Your participation should take approximately 90 minutes and your compensation will be $50. Please note that additional compensation will not be provided in the unexpected event that the test lasts longer than 90 minutes.

Informed Consent: By signing this form, you agree that your participation is voluntary. You may discontinue participation at any time without any penalty or loss of benefits to which you are entitled. You should understand that you have the right to ask questions at any time and that you can contact Liz Mazzae or Mark Flick at (937) 666-4511 for information about the study and your rights. By signing this form you also certify that all personal and vehicle information provided by you to persons associated with this study has been true and accurate.

Risks: During your participation in this study, risks have been carefully minimized since your driving will be performed on controlled roadways and on a large, controlled, open vehicle handling area. Consistent with good driving practices, there will be an in-vehicle experimenter who has the capability of safely bringing the vehicle to a stop. You should understand that in the event of physical injury resulting directly from the research procedures, no compensation will be available in the absence of negligence by a Transportation Research Center, Inc. or Vehicle Research and Test Center employee. However, the Transportation Research Center, Inc has emergency medical technicians on the facility which can be at the test site within five minutes.

Confidentiality: With the exception of information contained in the video (see below), all personal information gathered in this study will be kept confidential. Your name and personal identity information will not be associated with any data. You should understand that, for scientific, educational, or outreach purposes, a video recording (including full-face view) and/or engineering data from your drive may be used, in perpetuity.

Waiver of Confidentiality: A record of your responses and driving performance will be maintained for future use. This record will be kept confidential and will be stored without reference to your personal identity. By signing the waiver statement below, you agree that NHTSA shall have unrestricted use of the video tape, containing views of your face, and engineering data associated with the video tape, and may disseminate the video tape for education, outreach and research purposes, in perpetuity.

I have discussed the above points with the research participant or the legally authorized representative. It is my opinion that the subject understands the risks, benefits, and obligations involved in participation in this project.

____

Investigator Date Witness Date

INFORMED CONSENT FORM

Project Title: Normal Driver Data Collection
Principal Investigators: Liz Mazzae

I certify that all personal and vehicle information provided by me to TRC employees and others associated with this project during the pre-participation phone interview and the introductory briefing was true and accurate to the best of my knowledge.

I certify that I have been informed about the study in which I am about to participate. I have been told the procedures to be followed and how much time and compensation is involved. I have also been told that all records which may identify me will be kept confidential, except that I understand and agree that for scientific, educational, or outreach purposes a video tape of my drive which will contain views of my face may be used and disseminated by NHTSA in perpetuity, but names and other personal identifiers will not be used.

I understand that I may be required to perform tasks that may be encountered in a variety of driving conditions. It has been explained to me that the study will be conducted on a controlled track and that the risk of a crash is minimal.

I have been given adequate time to read the attached summary. I understand that I have the right to ask questions at any time and that I can contact Liz Mazzae or Mark Flick at (937) 666-4511 for information about the research and my rights.

I understand that my participation is voluntary and that I may refuse to participate or withdraw my consent and stop taking part at any time without penalty or loss of benefits to which I may be entitled. I hereby consent to take part in this project.

____

Signature of the Participant Date

10.4. APPENDIX D: SUBJECT DATA FORM

SUBJECT DATA FORM

TEST #	COND. #	TTC	INCURSION	VEHICLE	BRAKES	INSTRUCTION	PRACTICE
			PARTIAL				

DATA FILE:	
DATE:	
TIME:	
SUBJECT NUMBER:	
SUBJECT NAME (First only):	
AGE:	

OBSERVED SUBJECT CONDITION:	PRE-PARTICIPATION (Pre-briefer complete)	POST-PARTICIPATION (Post-briefer complete)
Observation of excessive shortness of breath?		
Observation of recent alcohol consumption or drug use?		
Observation of weakness, lack of coordination, or feebleness that could be hazardous?		
Observation of mental disorders, psychiatric conditions, disorientation, illogical or clouded thinking, or inability to comprehend or follow instructions?		
Observation of abnormal nervousness?		
Describe subject's mood or attitude (e.g., pleasant, jovial, unhappy, displeased)		

10.5. APPENDIX E: OUTLINE OF POINTS COVERED IN ABS INSTRUCTION VIDEO

1.0 Intro

Text and voice preceding ABS segment:
This videotape will provide you with information regarding the safety features of the VRTC test vehicles used in this research project. The car you will be driving today is equipped with manually operated seat belts, an antilock brake system (or "ABS" for short) and driver- and passenger-side air bags. The information that follows will help you understand the function and operation of these safety features.

2.0 ABS video segment

Summary of points covered in the video:

1.) What does ABS do?
   - It does not necessarily shorten stopping distances
   - Wheel lockup is kept to a minimum, no skidding
   - Helps maintain steering control of vehicle
   - Activates on rain, snow, ice, gravel, sand, loose surfaces, and bumps
   - Also activates on hard dry surfaces with hard enough braking

2.) How do you use it?
   - Do not pump brakes, maintain constant firm pressure
   - Make sure seat is adjusted so brake can be applied fully
   - Keep the vehicle's load equally distributed between axles for best results

3.) What will you feel or notice?
   - Ratcheting, grinding noise along with brake pedal vibration

4.) How does it work?
   - Brake system: brake input, wheel speed sensors, HCU, ECU (brain), modulated

5.) ABS self checks
   - Warning light system
   - ABS Self-test: Occurs the first time when the vehicle reaches 8 mph after vehicle ignition. Driver will hear ratcheting, grinding noise along with brake pedal vibration

3.0 Air bag segment:

(Text and voice) Another safety feature of the vehicle you will be driving today is driver- and passenger-side air bags. In the event of a severe impact, a vehicle's air bags are designed to activate in such a manner as to shield the driver and front-seat passenger from serious injury. In order for an air bag to be effective in protecting a vehicle occupant, the person must be wearing a seat belt properly.

Video of belted child sled test, voice-over as follows:
What you see in this film footage of a sled crash test illustrates how an air bag can restrain a properly belted occupant in the event of a crash.

Text and voice preceding second air bag (unbelted adult) segment:
When a front-seat occupant is unbelted or is wearing a seat belt incorrectly, he or she is subject to unrestrained movement and may sustain unnecessary injury, as can be seen in the test footage that follows:

Video of unbelted adult static test.

4.0 Seat belt segment:

(Text and voice) The vehicle you will be driving today is equipped with manually operated seat belts. To ensure your safety, you are required to wear a seat belt at all times when driving or riding as a passenger in a vehicle on TRC property.

5.0 Closing:

(Text and voice) Thank you for your attention. Please drive safely!

10.6. APPENDIX F: SCRIPT FOR PRE-RECORDED CD INSTRUCTIONS IN DRY PAVEMENT TESTING

LVABS Dry Pavement Test SUBJECT INSTRUCTIONS

(Make sure that appropriate CD has been inserted, Conventional or ABS)

In-Vehicle Experimenter: "I will be playing some recorded instructions for you at different times throughout your drive, so please pay attention. Here's the first set of instructions..."

Ø PLAY TRACK 1 BEFORE LEAVING THE PARKING LOT.
TRACK 1: "Please adjust your seat and mirrors, and put on the seat belt. This vehicle is equipped with manual seat belts, air bags, and *(conventional* brakes, *an antilock* brake system). You will be asked to drive over a set course for approximately 30 minutes. The in-vehicle observer will direct you where to drive. If you become uncomfortable at any time, let the observer know. You will now proceed to the area where you'll be driving."
***(Direct them to the VDA.*)**

Ù (BRAKE PRACTICE, IF APPROPRIATE) DIRECT THEM TO JENNITE. MAKE THEM STOP AND PLAY TRACK 2.
TRACK 2: "Ahead of you is a course marked by cones. Please approach the coned lane at 35 mph. Drive through the lane maintaining 35 mph and when you reach a certain point, you will be told to "brake". At that time, you should brake and steer the vehicle as needed to avoid the cone centered ahead of the lane. You will not be told how to avoid the cone. Just do whatever you feel is appropriate to avoid it. You'll do this 3 times."

Ú GO DOWN EAST SIDE, TURN RIGHT ALONG GRASS AND STOP AT FAR EDGE OF JENNITE. PLAY TRACK 3.
TRACK 3: "You will be turning left onto a two-lane road ahead of you. Watch for other vehicles already on this road as other people are participating in this study today just as you are. Drive normally and maintain 45 mph at all times. Do not pass other vehicles on this road. Don't worry about other traffic present as they will not interfere with your driving."
DIRECT THEM TO THE FIGURE 8.

Û PLAY TRACK 4 AS YOU"RE COMING OUT OF THE SOUTH LOOP THE 2ND TIME.
TRACK 4:
"This vehicle is equipped with a Laser Rangefinder system. On the dashboard, there is an electronic display which indicates the distance between this vehicle and a vehicle ahead of you. Please monitor this display and do you your best to maintain the value at "200 ft" WHILE maintaining the 45 mph speed limit. The display may give false readings in curves due to roadside obstacles. If the distance readings are obviously inaccurate, then just focus on driving at 45 mph.

For the rest of your drive, you will be provided with no further instruction. Please focus on maintaining 45 mph using your speedometer."

10.7. APPENDIX G: SCRIPT FOR PRE-RECORDED CD INSTRUCTIONS IN WET PAVEMENT TESTING

LVABS Wet Pavement Test SUBJECT INSTRUCTIONS

(Make sure that appropriate CD has been inserted, Conventional or ABS)

In-Vehicle Experimenter: "I will be playing some recorded instructions for you at different times throughout your drive, so please pay attention. Here's the first set of instructions..."

Ø PLAY TRACK 1 BEFORE LEAVING THE PARKING LOT.
TRACK 1: "Please adjust your seat and mirrors, and put on the seat belt. This vehicle is equipped with manual seat belts, air bags, and *(conventional* brakes; *an antilock* brake system). You will be asked to drive over a set course for approximately 30 minutes. The in-vehicle observer will direct you where to drive. If you become uncomfortable at any time, let the observer know. You will now begin your drive."

In-Vehicle Experimenter: DIRECT THEM TO TURN RIGHT OUT OF THE PARKING LOT AND GO DOWN THE ACCESS ROAD TOWARD THE GATE; TURN INTO Bldg. 30 LOT and TURN AROUND. TAKE ACCESS ROAD BACK TOWARD VRTC. DIRECT THEM TO THE VDA.

Ù GO ACROSS VDA IN FRONT OF POLE BARN. TURN LEFT AND DRIVE ALONG WEST SIDE OF VDA. PLAY TRACK 2 AS SOON AS THEY TURN ALONG WEST SIDE.
TRACK 2: "In a moment you will begin driving on a two-lane road. Watch for other vehicles already on this road as other people are participating in this study today just as you are. Drive normally and maintain a speed of 35 miles per hour at all times. Do not pass other vehicles on this road. Other traffic may be present near the area in which you are driving but they should not interfere with your driving. Come to a complete stop when you see an orange traffic cone ahead of you to the right of your vehicle. When stopped, watch for other traffic and then turn left onto this road as soon as it is clear to do so."

Ú PLAY TRACK 3 *as they are driving RIGHT* AFTER YOU PASS THROUGH THE INTERSECTION THE 2nd TIME.
TRACK 3: "This vehicle is equipped with a Laser Rangefinder system. On the dashboard, you'll notice an electronic display. This display indicates the distance between your vehicle and a vehicle ahead of you. Please monitor this display and do you your best to maintain the value at the specific distance which the in-vehicle experimenter will tell you **WHILE** maintaining the 35 mile per hour speed limit. The distance display may give false readings in curves due to roadside obstacles such as guard rail. If the distance readings are obviously inaccurate, then just focus on driving at 35 miles per hour. (Pause) For the rest of your drive, you will be provided with no further instruction. Please focus on maintaining 35 miles per hour using your speedometer."

In-Vehicle Experimenter: Tell subject to maintain a distance of 200 feet using the laser distance display!

10.8. APPENDIX H: **IN-VEHICLE LOG SHEET**

IN-VEHICLE LOG SHEET

TEST #	SUBJECT #	SUBJECT GETS BRAKING PRACTICE?	FILE NAME

Ambient light conditions: Sunny Clear Partly cloudy Cloudy/Overcast

If rec'd 'Practice', did they activate ABS during practice? YES NO N/A

Time subject started Figure 8 pattern: __________ AM PM

Observed speed of subject vehicle at intersection: ____________ MPH

Anticipated crossing vehicle? YES NO DON'T KNOW

Subject reaction: NONE STEER LEFT STEER RIGHT

ACCELERATE BRAKE BRAKE (LOCKUP) ....

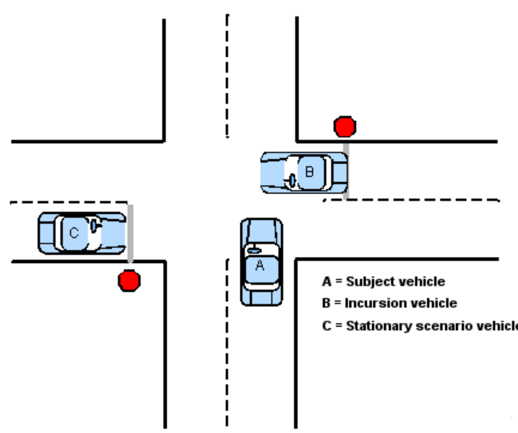
Stability:
_____Did not skid
_____Skidded less than 30 degrees of rotation
_____Skidded laterally clockwise direction
_____Skidded laterally counter-clockwise direction

Lane Deviation:
_____Vehicle stayed in right lane
_____Vehicle stayed on roadway but entered left lane
_____Vehicle stayed on roadway but over ½ entered left lane
_____Vehicle stayed on roadway but entered right shoulder
_____Vehicle stayed on roadway but over ½ entered right shoulder
_____Vehicle departed roadway to the left
_____Vehicle departed roadway to the right

ABS activated? NO YES

Impact? NO YES

(If Impact, circle impact location in diagram) (Illustrate vehicle path during incursion scenario:_



COMMENTS:

10.9. APPENDIX I: **POST-DRIVE DEBRIEF**

Post-Drive Debrief

(As you walk them into the building:)
"How was your drive today?"
"Did you have a crash?"

As described in the information summary earlier, the purpose of this study is to collect data on how average people drive. We are interested in learning such things as how well average drivers are able to steer and maintain their vehicle's position within the lane and how well they are able to accurately maintain a certain speed. We are also interested in how drivers react in certain conflict maneuvers. This is why we included the last event where the car drove suddenly into the intersection. This is a Government sponsored study. The US Government is interested in learning about how people drive in order to find ways to help drivers and improve cars in an effort to prevent automobile crashes in the future. The test track offers a controlled and safe environment in which to study these types of situations. We hope that you agree that this was a safe test.

We are not grading your performance in this study. We are merely collecting data from a large number of people and then looking at it as a whole. The event you experienced was designed to require an extremely severe braking and/ or steering response. It was expected that very few people, if any, would be able to avoid colliding with this car. This should in no way be considered a reflection of your ability to drive or avoid an accident. After this test program is over, your name and personal information that you provided to us will no longer be linked to your data.

** LASTLY, if you know anyone else who may be planning to participate in this study, please do not discuss any of the details of your drive with them until after they have participated. It is important that they drive in the study without any advance information about the drive. Anyway, we have 24 different tests that we're conducting so it's likely that they will not get the same test, but it's important that they don't come in with expectations as to what the drive will be like.

We would like to again thank you for coming in and helping us today. We have a brief questionnaire for you to complete. When you're finished, we will pay you and escort you back to your vehicle.

10.10. APPENDIX J: POST-DRIVE QUESTIONNAIRE

POST-TRIAL QUESTIONNAIRE PART 1
INFORMATION

DATE: _________ SUBJECT #: _____ TEST #: _____ CONDITION #: _______

As part of this study, it is useful to collect some personal information regarding each participant's background. The following questions will ask about you, your driving patterns, and the vehicle(s) which you drive. Please read each question carefully and mark only one response unless otherwise indicated by the question. If none of the responses are appropriate, leave it blank. If anything is unclear, feel free to ask for help. Remember, your participation is voluntary and you have the right to skip **ANY** question. Thank you for your participation.

1) What is your birth date? _________/________/
Month / Day / Year

2) What is your gender?
- Male
- Female

3) What is your marital status?
- Single
- Married
- Separated or Divorced
- Widowed

4) What is your highest level of education completion?
- Primary School
- High School Diploma
- Technical School
- Associates Degree
- Bachelors Degree
- Some Graduate or Professional School
- Graduate or Professional Degree

5) What is your present employment status?
- Full-time
- Part-time
- Unemployed
- Retired
- None of the above

6) What is your occupation (e.g. teacher, doctor, housewife (if applicable))?

7) For which of the following vehicles do you currently hold a valid driver's license <u>within</u> the United States? (Check all that apply)

Vehicle Type	Year When FIRST Licensed (Approximately)	Country of License (If other than U.S.)
‘ Car		
‘ Motorcycle		
‘ Truck		
‘ Other:		

8) Approximately how many miles do you drive per year in each vehicle type? (Check only one for each vehicle type)

Car	Motorcycle	Truck	Other:
‘ Under 2,000	‘ Under 2,000	‘ Under 2,000	‘ Under 2,000
‘ 2,000 - 7,999	‘ 2,000 - 7,999	‘ 2,000 - 7,999	‘ 2,000 - 7,999
‘ 8,000 - 12,999	‘ 8,000 - 12,999	‘ 8,000 - 12,999	‘ 8,000 - 12,999
‘ 13,000 - 19,999	‘ 13,000 - 19,999	‘ 13,000 - 19,999	‘ 13,000 - 19,999
‘ 20,000 or more	‘ 20,000 or more	‘ 20,000 or more	‘ 20,000 or more

9) How often do you drive?
- ‘ At least once daily
- ‘ At least once weekly
- ‘ Less than once weekly

10) Is any driving you do work-related? (This does not include traveling to and from work.)
- ‘ Yes
- ‘ No (skip to question 12)

11) If you answered yes to question 10, how many work-related miles do you drive per year?
- ‘ Under 2,000
- ‘ 2,000 - 7,999
- ‘ 8,000 - 12,999
- ‘ 13,000 - 19,999
- ‘ 20,000 or more

12) In which environment do you most typically drive?

‘ Rural highway	‘ City
‘ Small town	‘ High density city
‘ Suburban	‘ Highway / freeway

13) What speed do you typically drive at when the posted speed limit on a road is:

35 ________**45** ________**55** ________ **65**

14) When the following conditions or situations occur, how frequently do they keep you from driving? (Check the most appropriate answer for each condition)

	Frequently	Occasionally	Rarely	Never	Not applicable
At night	‘ =	‘ =	‘ =	‘ =	‘ =
In fog	‘ =	‘ =	‘ =	‘ =	‘ =
In rain	‘ =	‘ =	‘ =	‘ =	‘ =
In snow or sleet	‘ =	‘ =	‘ =	‘ =	‘ =
During rush hour	‘ =	‘ =	‘ =	‘ =	‘ =
On highway/freeway	‘ =	‘ =	‘ =	‘ =	‘ =
While smoking	‘ =	‘ =	‘ =	‘ =	‘ =
After drinking alcohol	‘ =	‘ =	‘ =	‘ =	‘ =
With children	‘ =	‘ =	‘ =	‘ =	‘ =

15) How comfortable do you feel when you drive in the following conditions or perform the following maneuvers? (Check the most appropriate answer for each condition)

	Very Comfortable	Slightly Comfortable	Slightly Uncomfortable	Very Uncomfortable	Not Applicable
At night	‘ =	‘ =	‘ =	‘ =	‘ =
In fog	‘ =	‘ =	‘ =	‘ =	‘ =
In rain	‘ =	‘ =	‘ =	‘ =	‘ =
In snow or sleet	‘ =	‘ =	‘ =	‘ =	‘ =
During rush hour	‘ =	‘ =	‘ =	‘ =	‘ =
On highway/freeway	‘ =	‘ =	‘ =	‘ =	‘ =
While smoking	‘ =	‘ =	‘ =	‘ =	‘ =
After drinking alcohol	‘ =	‘ =	‘ =	‘ =	‘ =
With children	‘ =	‘ =	‘ =	‘ =	‘ =
In high density traffic	‘ =	‘ =	‘ =	‘ =	‘ =
When passing other cars	‘ =	‘ =	‘ =	‘ =	‘ =
When changing lanes	‘ =	‘ =	‘ =	‘ =	‘ =
When making left turns at uncontrolled intersections	‘ =	‘ =	‘ =	‘ =	‘ =

16) How did you learn to drive? (Check all that apply)
‘ Formal instruction (e.g. driver's education class)
‘ Informal instruction (e.g. from a relative or friend)

17) Have you ever participated in any special driving schools (e.g. AARP or insurance courses, racing school, or as part of law enforcement training)?
‘ Yes (Please describe)
‘ No

18) What type of automobile do you drive most often?

Make (e.g. Ford, Toyota)
Model (e.g. Escort, Celica)
Yea

19) Which of the following features does this automobile have? (Check all that apply)
‘ Air Bag
‘ Antilock Brakes
‘ Automatic Transmission
‘ CB Radio
‘ Cellular Phone
‘ Manual Transmission
‘ Power Brakes
‘ Power Steering
‘ Radar Detector
‘ Other technologies (e.g. trip computer, moving-map display).
Please list these here:
‘ None of these

20) How many vehicles have you driven on a regular basis over the last 5 years?
‘ 1
‘ 2
‘ 3
‘ 4
‘ 5 or more

21) Do you personally do the maintenance on your vehicles (you personally, not your spouse or other)?
- ‘ Yes, I do perform maintenance on my own vehicle
- ‘ No

22) Regardless of what road you were on, have you ever had to brake your vehicle so sharply that your brakes locked and you went into a skid (If so, describe the road, vehicle, speed, and environmental conditions at that time)?

23) As in question 22, describe any other instances where you may have had a braking problem, a run-off-the-road problem, or any problems which may have occurred as a result of trying to stop your vehicle abruptly:

24) If you have ever driven off the road to avoid a collision, please describe the situation including your reasoning behind the decision to drive off road:

POST-TRIAL QUESTIONNAIRE PART 2
DRIVE

** Please circle your responses for all yes/no questions

1) What do you think the purpose of today's drive was?

2) At any point during the driving task did you begin to drive more carefully than you normally would in typical daily driving?

Yes No

If yes, describe what happened to make you start driving more cautiously?

3) During the driving task, did you feel that the other vehicles you encountered behaved the way you would expect them to in a real world driving situation?

Yes No

Explain:

4) Remember when you approached the intersection and the vehicle pulled out in front of you. Did this sequence of events seem realistic?

Yes No

If not, why not?

5) When you approached the intersection, did you anticipate or expect that the car might pull out in front of you?

Yes No Explain:

6) When you approached the vehicles at the intersection, did you react to them in the same manner as you would react vehicles in a similar scenario in a real world driving situation?

Yes No If not, why not?

7) Did you think that the vehicle which pulled out in front of you was:

a) a real car; the same one which had been sitting there the whole time you were driving in the study

b) a real car, but different than the one that was there previously

c) a fake car

d) other ____

8) If you realized that the car was fake, at what point did you realize it was fake?

a) as soon as you spotted it visually as you approached the intersection;

Specify or describe the distance at which you realized it was fake: ________ feet

b) didn't realize it was fake until it started to pull out

c) didn't realize it was fake until I hit it

d) didn't realize it was fake until I drove around it after it pulled into the intersection

e) other ____

9) Did anything about the vehicle which pulled out in front of you seem strange or unrealistic? (Please explain.)

10) Were you startled by the vehicle pulling out in front of you? Yes No

Explain:

11) When the vehicle pulled out in front of you, describe your reaction in as much detail as possible. (When did you decide to react? What did you do to try to avoid a crash? Include mental processes, order of events, and other relevant information)

12) Why did you react the way you did when the vehicle pulled out in front of you (i.e. steering, braking, etc.)?

13) At any time when the vehicle was pulling out in front of you, did you notice where the driver of that car was looking?

Yes No

If yes, where was the driver looking?

14) Did you notice whether or not the driver of that car was the same person that was in the car located there previously?

Yes No Explain:

15) When you tried to avoid hitting this car, do you feel that you reacted as you would have during a real world situation as opposed to our test track environment?

Yes No If not, what would you have done differently? _______________.............................

16) If the situation on the test track environment (where the vehicle pulled out from the intersection) had occurred in the real world, what do you think would have happened?

|____________|____________|____________|________|________|__________|
1 2 3 4 5 6 7

1	2	3	4	5	6	7
I would have been able to avoid a crash			**Don't Know**		**I would not have been able to avoid a crash**	

17) Do you know what the initials "ABS" stand for? No Yes
If yes, what does it stand for?____________

18a) Was the test vehicle which you drove today equipped with ABS? No Yes

18b) If you braked to try to avoid hitting the car which pulled into the intersection in front of you, did you activate the ABS system while braking?
Yes No

If yes, describe how you knew the ABS was activated?

19) Have you ever activated an antilock brake system in ANY vehicle you have ever driven?

Yes No Explain:

20) In your opinion, does an anti-lock brake equipped vehicle provide an advantage over conventional braking during a similar situation (when a vehicle pulls out in front of you) in the real world? (Please circle your response)

Advantage (ABS is better) No Advantage (equal) Disadvantage (ABS is worse)

Please explain your response:

21) If the situation where the vehicle pulled out from the intersection had occurred in the real world, what would you have done? Please check the best answer.

I would have just steered to the right
I would have just steered to the left
I would have just braked in a straight line
I would have braked and steered to the right
I would have braked and steered to the left
I would have accelerated and steered to the right
I would have accelerated and steered to the left
I would not have done anything
I wouldn't have steered or braked
I am not sure
or other

22) Did the distance display on your dashboard distract you during the driving task? If so, please explain.

POST-EXPERIMENT QUESTIONNAIRE 3

Circle the number corresponding to the most appropriate response:

1) How did driving in the test vehicle compare to driving your vehicle?

1	2	3	4	5	6	7
Easier			Same			Harder

2) Rate the responsiveness of the test vehicle as compared to the responsiveness of your vehicle.

1	2	3	4	5	6	7
Moved too slow			Moved just right			Moved too fast

3) Rate your ability to stop the test car as compared to your car.

1	2	3	4	5	6	7
Stopped slower			Stopped the same			Stopped faster

4) Rate the feel of the brake pedal while braking in the test car compared to your car.

1	2	3	4	5	6	7
Too hard			Just right			Too sensitive

5) Rate how realistic the scenario in which the vehicle pulled out in front of you was as compared to something you might experience when driving on an actual road.

1	2	3	4	5	6	7
Not at all realistic			Somewhat the same			Very realistic

6) As you approached the intersection, did you expect the vehicle to pull out in front of you?

1	2	3	4	5	6	7
Did not expect the car to pull out			Not sure			Expected the car to pull out

7) Rate how realistic the vehicle which pulled out in front of you seemed to you.

1	2	3	4	5	6	7
Not at all realistic			Somewhat realistic			Very realistic

8) Rate your personal feeling about driving in this study.

|___________|___________|___________|___________|___________|___________|

1	2	3	4	5	6	7
Had a bad time			It was OK			Had a Good time

9) Rate how realistic the intersection seemed to you.

|___________|___________|___________|___________|___________|___________|

1	2	3	4	5	6	7
Not at all realistic			Somewhat realistic			Very realistic

Thanks again for your participation!
We hope that you enjoyed the experience.