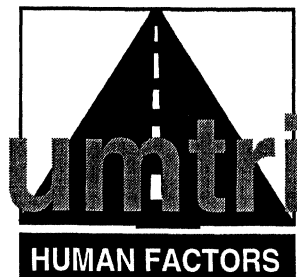


Technical Report UMTRI-99-14

May, 1999

Driver Behavior While Following Cars, Trucks, and Buses

Paul Green and Herbert Yoo



UMTRI The University of Michigan
Transportation Research Institute



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| 16. Abstract <p>A total of 16 drivers (8 ages 16-30, 8 ages 65 or older) drove a driving simulator at approximately 45 mi/hr (72 km/hr) while following either a car, pickup truck, school bus, or tractor trailer. They drove on a winding two-lane road as they normally would, but were instructed not to pass the lead vehicle. The variance of the speed of the lead vehicles was either low (4.2 mi/hr [6.7 km/hr]) or high (for the car and pickup truck only, 7.1 mi/hr [11.4 km/hr]). The subjects also identified signs when they appeared.</p> <p>In general, older drivers followed at a greater distance than younger drivers (469 vs. 282 ft [143 vs. 86 m]). Some older drivers followed so the lead vehicle would be out of sight (600 ft [183 m]). These following distances, corresponding to headway times of 4.3 and 7.1 s, are much greater than are reported from on-the-road studies.</p> <p>Although subjects followed cars about 10 percent closer than other vehicles, there were no other effects of vehicle type or its speed variability (within the range explored) on following distance. Further, both mean lateral position and the standard deviation of lateral position were unaffected by lead vehicle type or their speed variance, though there were significant individual differences. The lack of influence of vehicle characteristics may result from the absence of traffic following the subject (and a rearview mirror to see such) in this simulation, so the pressure to keep up with traffic was missing. This suggests that vehicle following studies may require simulations to include a rear visual channel.</p> | | | | | |
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Driver Behavior While Following Cars, Trucks, and Buses

UMTRI Technical Report 99-14
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1 ISSUES

1. What is the mean and standard deviation of the following distance as a function of lead vehicle type and lead vehicle speed variability?
2. Do drivers of all ages follow vehicles in the same manner?
3. Do the experimental data agree with the literature?
4. What are important considerations in following studies in simulators?

2 METHOD (simulator)

"Follow the vehicles as you normally would in real driving and read all signs."



Winding road driven at 45 mi/hr

Subjects

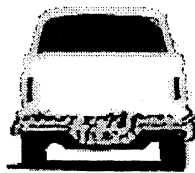
| | Young | Old |
|-------|-------|-----|
| Women | 4 | 4 |
| Men | 4 | 4 |

Test conditions

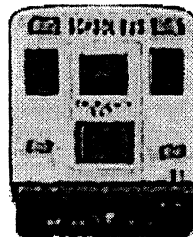
| Vehicles | Lead vehicle speed variance | |
|-----------------|-----------------------------|------|
| | low | high |
| Car | ✓ | ✓ |
| Pickup truck | ✓ | ✓ |
| School bus | ✓ | |
| Tractor trailer | ✓ | |



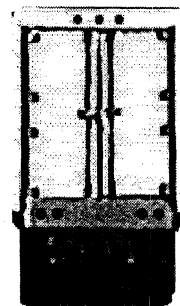
Car



Pickup truck



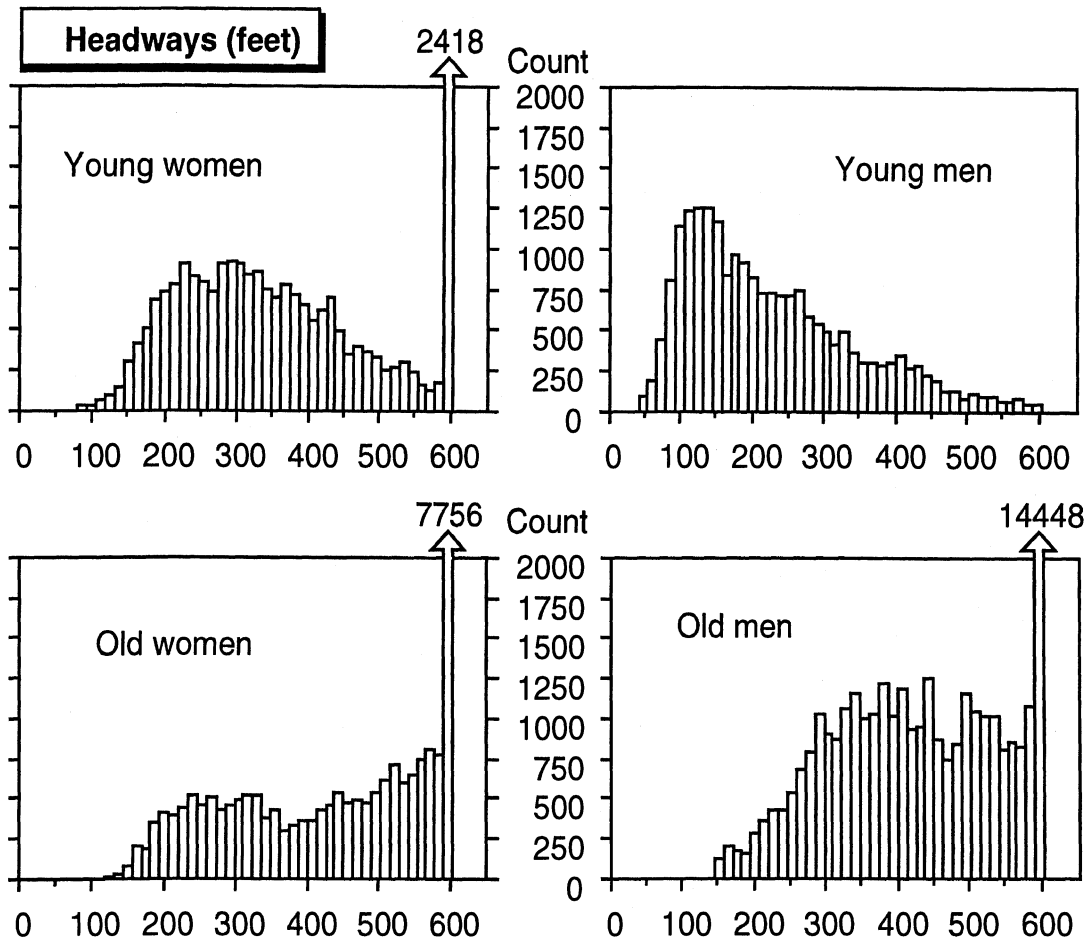
Bus



Tractor trailer

3 RESULTS

If the headway > 600 ft (the maximum sight distance), 600 ft was assumed, a critical assumption. Other strategies to compensate for this behavior and provide usable results proved problematic. Therefore, the results should be viewed as conservative estimates. Using ANOVA, the means for each subject, block, run combination were examined.



| | Age | Sex | Age*Sex | Subject | Vehicle |
|-----------------------|-------------------------------|-----|---------|--------------------------|--|
| Mean headway | * young = 286 old = 473 | * | * | * range: 134 - 490 | * car=359, pickup =392 bus = 385, trailer = 392 |
| S.D. headway | * young = 71 old = 61 | * | * | * range: 18 - 93 | Values (feet) of significant (*) selected effects |
| Lateral position | * young = 5.9 old = 6.2 | | * | * range: 5.2-6.9 | |
| S.D. lateral position | | * | * | * range: 0.4-12.0 | |

Note: 1 ft = 0.3048 m

4 CONCLUSIONS

1. Small effect of vehicle type (following distance for cars was 10% less).
2. Speed variance had no effect on following distance.
3. Headway distances for old drivers were double young drivers. Age interacted with sex.
4. Headways measured were much larger than those in the literature.
5. Simulator limitations (no vehicle following subject, 600 ft max sight distance, image jitter when following closely) may have inflated sight distances.

PREFACE

The purpose of this project was to examine driver following behavior in a simulator, and as part of that process, upgrade the UMTRI driving simulator. Independent of the primary research questions, there were two major technical challenges: (1) getting the lead vehicle to maneuver in a realistic manner, and (2) scanning and editing the lead vehicle images so that they appeared realistic. The authors would like to thank Alan Olson of UMTRI for his efforts to design and implement the autopilot routines for controlling lead vehicles. Edgar Manalo played a major role in creating the graphics files for lead vehicles and constructing the experiment scenarios.

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INTRODUCTION

Within the scope of ITS (Intelligent Transportation Systems), there is significant interest in implementing new systems to make driving safer, more efficient, and more enjoyable. Products are being developed to provide navigation assistance, warn drivers of various types of collisions, provide information on various motoring-related services, provide for automatic and semiautomatic lane keeping and speed control, and so forth. Some of these products could radically change the way people drive. If that is the case, then there is a need for a fundamental understanding of how people drive, that is, to develop a science of driving. First, to determine where improvements are possible, there is a need to know what drivers do now. Second, when prototypes of new systems are available, baseline data are needed to assess if any change has occurred. Finally, there is a more general need to develop models of how people drive, allowing design alternatives to be assessed using inexpensive computational methods rather than expensive experimental evaluations (van Winsum, 1991). As an example, such data have proven to be useful in predicting the effectiveness of alternative collision warning algorithms (Farber, 1995). To collect data on driving, cost-effective tools will be needed including instrumented vehicles, road monitoring systems, and driving simulators.

Evidence from the Literature on Crash Statistics

One of the more commonly referred to sources of crash statistics is the paper by Massie, Campbell, and Blower (1993). That paper proposes a collision topology, a scheme for categorizing crash scenarios for the purpose of developing collision avoidance strategies. Their topology considers the number of vehicles involved (single versus multiple), the driving situation (signalized intersection, signed intersection, nonintersection), and the geometry of the collision for multiple vehicles (same direction, opposite direction, crossing paths). Depending on the data base used as a source, approximately 18-20 percent of the crashes considered involved multiple vehicles moving in the same direction not at an intersection. While many of those crashes involved lead vehicles that were stopped or slow moving, there were other types of rear-end collisions as well. (See also Eberhard, Moffa, and Swihart, 1996.) Other sources indicate significant opportunities for reducing the frequency and severity of rear-end crashes (Knipling, Mironer, Hendricks, Tijerina, Everson, Allen, and Wilson, 1993; Farber, Freedman, and Tijerina, 1995; Eberhard, Moffa, and Swihart, 1996).

Studies of How People Actually Follow Traffic

The need to understand car following has been recognized for some time, and the body of literature on this topic is considerable. Following is a tabular summary (Table 1) of the research to date. Studies on following behavior fall into four categories: (1) normative evaluations of actual following distances, (2) studies that attempt to model following behavior, generally using control theory, (3) studies that emphasize perceptual issues such as the visual angle of the lead vehicle and speed perception, and (4) studies that concern the evaluation of adaptive cruise control (ACC), headway warning, and collision avoidance devices. Notice that the number of studies with baseline data was limited when this project was started. Further, none of

the studies examined the influence of the type of vehicle being followed, the focus of this experiment. As a whole, these studies suggest that drivers typically follow vehicles with time headways on the order of 1 to 2 s, though headways of up to 6 s are not unusual. They also suggest that headways of older drivers are about double those of younger drivers.

Table 1. Previous Studies of Following Behavior

| Source | Method | Results | Comments |
|--|--|--|---|
| Sleight (1961) | 25 drivers follow lead vehicle on unopened expressway (30, 50 mi/hr), drive normally, with maximum safety, and emergency conditions | <ul style="list-style-type: none"> means for 30, 50 mi/hr normal (94, 184 ft) emergency (48, 90 ft) safety (98, 218 ft) | <ul style="list-style-type: none"> headway determined using filmed targets |
| Braunstein, Laughery, & Siegfried (1963) | follow vehicle on NY State Thruway (expressway), subjects were 3 technicians | <ul style="list-style-type: none"> emphasis on developing computer model, includes flowchart but no software some sample parameters given | <ul style="list-style-type: none"> size of target on film used to determine distance |
| Rockwell & Ernst (1965) | 2 studies (8 and 16 subjects) on expressway (50-65 mi/hr), lead vehicle accelerated, decelerated or speed followed sine wave | <ul style="list-style-type: none"> minimum time headway was inversely proportional to speed ($t_{min} = 0.0205 + (0.205/v)$, t_{min} in minutes, v in mi/hr) | used cable reel between vehicles to measure distance (see also Gantzer and Rockwell, 1967) |
| Fenton & Rule (1971) | mathematical analysis | <ul style="list-style-type: none"> application of feedback control theory | |
| Janssen & Nilsson (1990) | fixed base simulator, 2 lane winding road driven at 60, 70, 80, or 90 km/hr, 56 drivers, driver with no collision avoidance system then with one | <ul style="list-style-type: none"> numerous histograms showing time headways, speed profiles typical was sharp rise from 0 to 1 s, sharp drop to 2 s, constant level to 6 s, then drop off to 10 s | see paper for details on collision avoidance system effectiveness |

| Source | Method | Results | Comments |
|--|--|---|---|
| McGehee, Dingus, Horowitz, Oberdier, & Parikh (1993) | 1990 Olds Trofeo with headway display driven on rural roads by 108 drivers (young, middle, old age groups) | mean time headways: <ul style="list-style-type: none"> • 1.42 s without display, 2.68 s with display • day-young drivers 0.68 s, day-middle 1.80 s, day-old 1.55 s, dusk-young 0.74 s, dusk-middle 2.54 s, dusk-old 1.60 s | <ul style="list-style-type: none"> • big difference due to display • no explanation of why middle aged times were long relative to other age groups |
| Nirschl & Eck (1994) | BMW 730iL over 190 km highway course, 4 drivers | <ul style="list-style-type: none"> • focus on taxonomy of situations for ACC • approach and follow at just over 1.0 s | reports 3 types of drivers: constant distance, constant time, behavior varies with road |
| Ota (1994) | 31 young drivers, highway (50 km/hr) and expressway (80 km/hr), following distances: 1. comfortable, 2. dangerous, 3. minimum safe, 4. neither too far or near | <ul style="list-style-type: none"> • for 3 speeds (50, 60, 80 km/hr): comfortable: 1.25, 1.3, 1.4 s dangerous: .55, .60, .65 s min. safe: 1.15, 1.0, 1.15 s not far or near: 1.65 1.60, 1.65 s | • considerable discussion of personality traits and headway |
| Hattori, Asano, Iwama, & Shigematsu (1995) | driver follows lead vehicle at 80-100 km/hr | <ul style="list-style-type: none"> • develops 3 state model of following (following, braking, coasting) • emphasis on state transition | <ul style="list-style-type: none"> • includes situations of approaching a slower lead vehicle • model appears useful |
| Sayer, Fancher, Bareket, & Johnson (1995) | 1993 Saab 9000 Turbo, 3 drives (baseline, manual cruise, ACC), 55 mile expressway route, 36 drivers (3 age groups) | <ul style="list-style-type: none"> • provides velocity histograms (mean 66.3 mi/hr, sd=5.3 mi/hr) • # brake applications/mi (5.8/mi, sd=3.6/mi) | |

| Source | Method | Results | Comments |
|---|--|--|---|
| Suetomi, Kido, Yamamoto, & Hata (1996) | 45 young male drivers, Mazda motion-base simulator, also collected on road data | <ul style="list-style-type: none"> • headway = $20 + 0.67$ speed (km/hr) • simulator and on road data for 4 degrees of freedom (DOF) motion were comparable • time headways: peak at 1.5 s, symmetrical from 1 to 3 s, some trail out to 6 s | <ul style="list-style-type: none"> • emphasis on value of motion: 0 DOF leads to braking too hard, 3 DOF leads to overshoot, 4 DOF gives reasonable behavior |
| van Winsum & Heino (1996) | U of Groningen simulator, 2 lane roads driven at 40, 50, 60, or 70 km/hr, 54 young & middle age drivers, part 1 was following, part 2 involved braking | <ul style="list-style-type: none"> • mean time headway was 1.0 s regardless of lead vehicle speed • time headways for individual drivers were consistent | <ul style="list-style-type: none"> • see paper for braking results |
| Allen, Magdaleno, Serafin, Eckert, & Sieja (1997) | <ul style="list-style-type: none"> • midsize sedan drive around Ford test track (40-60 mi/hr) by 12 Ford employees • Saab 9000 on open road (60 mi/hr, 36 drivers, 3 age groups) | <ul style="list-style-type: none"> • crossover model for speed control modified to yield extended crossover model with additional headway error terms • mean headway of 85 ft on test track, 122 ft on open road • 97 ft for young, 121 for middle, 188 for old | <ul style="list-style-type: none"> • time histories of throttle, speed, range, etc. transformed and plotted in frequency domain • very strong theoretical model |
| Fairclough, May, and Carter (1997) | 16 drivers on open road, drive at 56, 72, 88, and 105 km/hr, with and without headway system, in peak or off peak traffic | <ul style="list-style-type: none"> • 3 types of drivers: close followers (mode 1.0 to 1.5 s), medium, & cautious followers (mode 1.5 to 2.0 s) (as shown in histograms) | <ul style="list-style-type: none"> • examined headway feedback • data on overtaking |

Issues

The goal of this project is to determine how the distribution of following distances and lane variance is affected by the size of the vehicle ahead and its speed variability. This experiment was conducted in a driving simulator. Hirose, Matsumoto and Inomata (1976) have shown a fairly good correspondence between following data collected on the road and following data collected in a moving belt driving simulator.

More specifically, this experiment examined the following issues.

1. What is the mean and standard deviation of the following distance for each vehicle type?

Common experience suggests drivers follow larger vehicles at a greater distance so they can see around them.

2. How does speed variance of the lead vehicle affect following distance?

The more erratic the lead vehicle, the greater the following distance.

3. Do drivers of all ages follow vehicles in the same manner?

Common experience and the literature indicate older drivers will follow at greater distances.

4. Do the experimental data agree with the literature? If there are differences, how can they be explained?

5. What are important considerations in following studies in simulators?

TEST PLAN

Overview

The subjects drove a simulated vehicle while following other simulated vehicles and identifying roadside signs. The lead vehicles varied in type and speed variance. Headway, speed, lateral position and other measures were recorded for each vehicle. Dependent variables (of the subject's car) examined were means and standard deviations of headway and lateral position.

Test Participants

Sixteen licensed drivers participated in this experiment, 8 men and 8 women. Within each gender bracket there were 4 older (65 years and above) and 4 younger (16-30 years) drivers. Participants were recruited using lists from previous UMTRI studies and from among friends of the experimenters. Two additional subjects were dropped, one due to illness and one due to a mistrial. All were paid \$20 for their participation.

Table 2 summarizes the characteristics of the subjects. Subjects reported driving 300 to 30,000 miles per year. Also obtained from subject reports are their ratings of driving aggressiveness, the lane driven most often on expressways, involvement in rear-end collisions, and how often they were stopped for speeding. One older male did not respond to these questions. This sample seems representative of U.S. drivers.

Table 2. Subject information

| | Female | | Male | | Young (8) | Old (8) | Total (16) |
|--|-----------------|------------------|-----------------|-----------------|-----------------|------------------|------------------|
| | Young(4) | Old(4) | Young(4) | Old(4) | | | |
| Mean age | 19.3 | 72.0 | 21.8 | 67.0 | 20.5 | 69.5 | 45.0 |
| Mean years of driving | 3.9 | 52.5 | 6.0 | 51.5 | 4.9 | 52.0 | 28.5 |
| Mean annual mileage | 12,000 | 5,200 | 4,875 | 17,250 | 8,438 | 11,225 | 9,831 |
| Exposure to simulator | 25% | 100% | 25% | 100% | 25% | 100% | 63% |
| Range of visual acuity | 20/15- 20/25 | 20/40- 20/100 | 20/13- 20/18 | 20/25- 20/35 | 20/13- 20/25 | 20/25- 20/100 | 20/13- 20/100 |
| Aggressiveness Rating | 5.8 | 4.8 | 5.3 | 4.0 | 5.5 | 4.4 | 5.0 |
| Lane driven most often: L-Left C-Center R-Right | | | | | | | |
| Rear-end collisions | 0% | 50% | 0% | 25% | 0% | 38% | 19% |
| Stopped for speeding | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

Notes:

- One older male subject did not respond to the last four entries of this table.
- Exposure to simulator: percentage who participated in previous simulator studies
- Aggressiveness rating: 1 = least aggressive and 9 = most aggressive (self rated)
- Rear-end collisions: percentage of sample that were involved in a rear-end collision
- Stopped for speeding: percentage stopped by police for speeding in the last 3 years

Test Materials and Equipment

Figure 1 shows the four vehicles the subjects followed during the experiment. These images were created by digitizing videotapes of 1/64 scale model vehicles. Each vehicle was put on a rotary table and was recorded at every two degrees to allow for multiple visual aspects for the driver as he/she would follow the vehicles. The vehicles were recorded with a blue background which was removed using Adobe Photoshop. The simulator software was upgraded to support rotating views of lead vehicles.

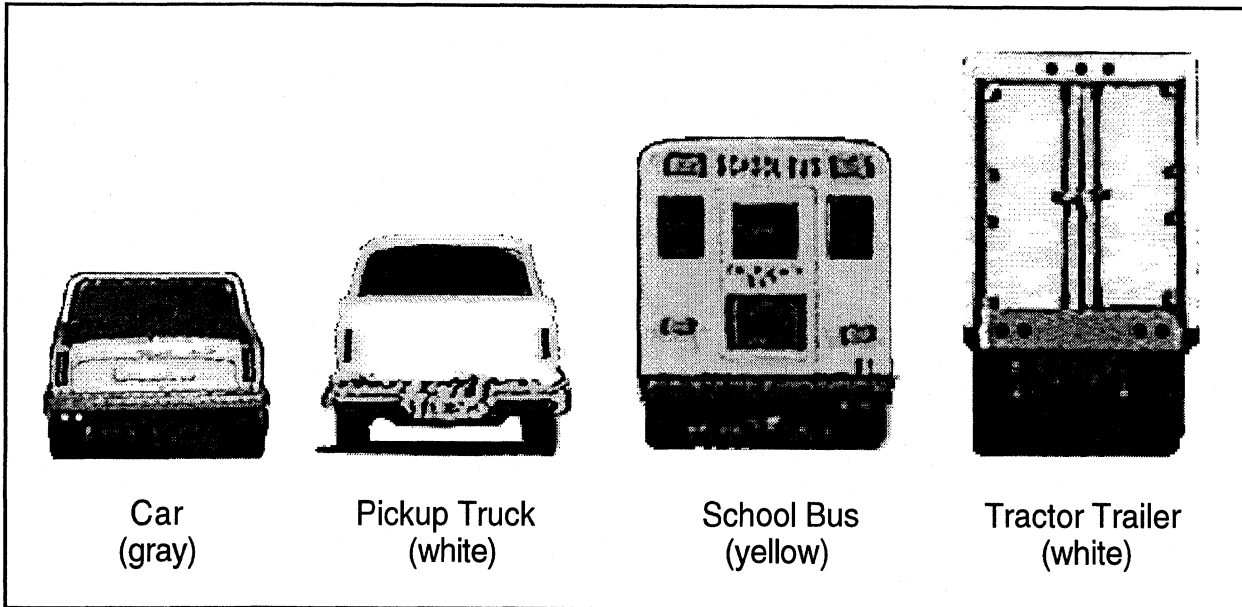


Figure 1. Vehicles subjects followed in the experiment

Figure 2 shows the rear area of each test vehicle determined two different ways. The car had the smallest rear area and the tractor trailer had the largest area, with the pickup truck and the school bus in between, respectively.

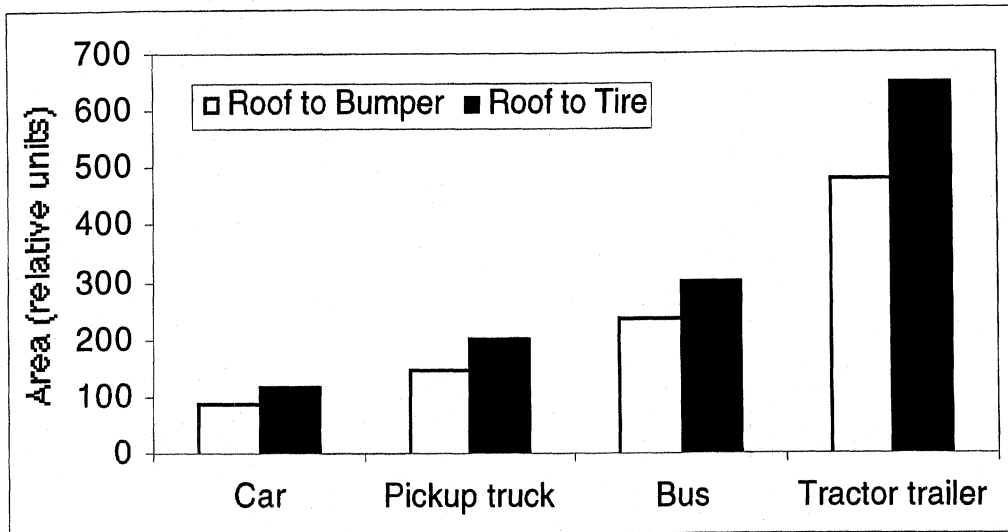


Figure 2. Vehicle rear area comparison

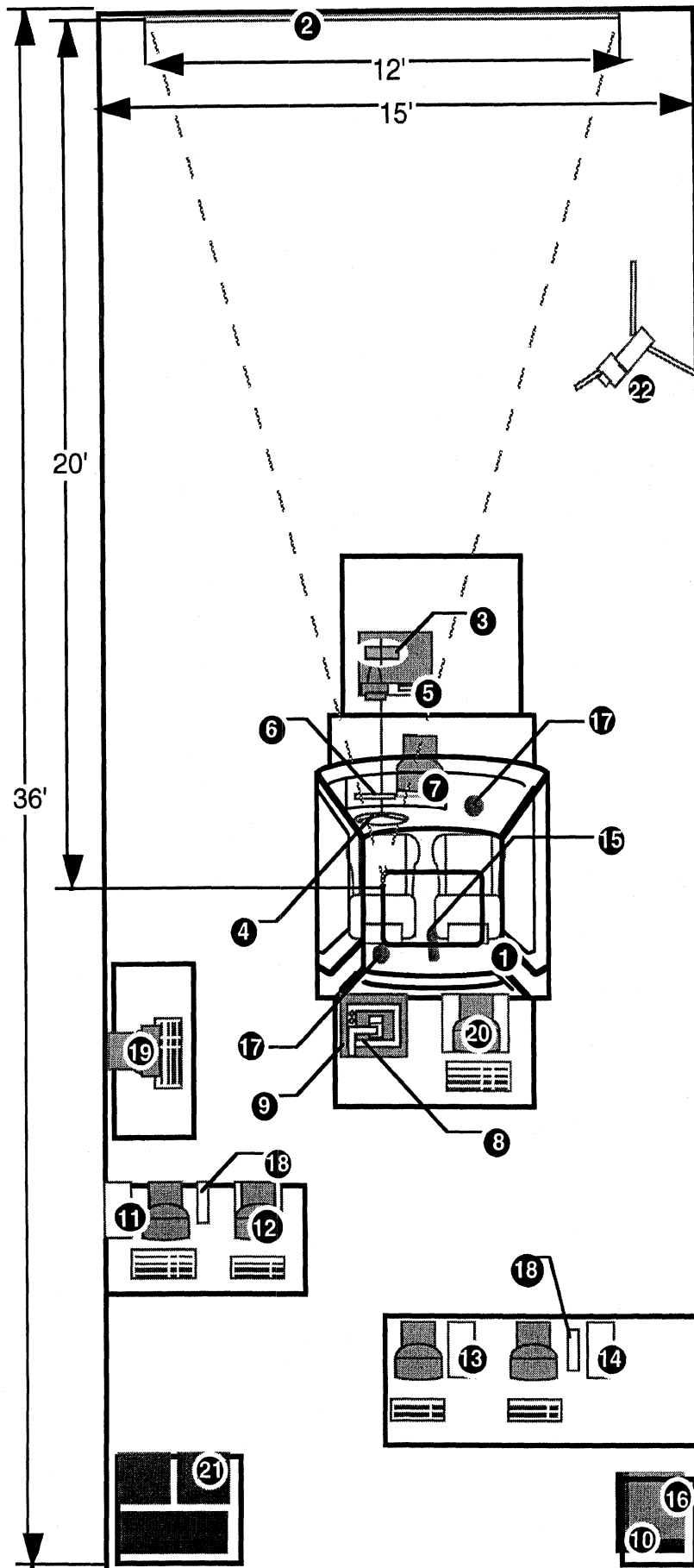
This experiment was conducted using the UMTRI Driver Interface Research Simulator, a low-cost driving simulator based on a network of Macintosh computers (Olson and Green, 1997). The simulator consists of an A-to-B pillar mockup of a car, a projection screen, a torque motor connected to the steering wheel, a sound system (to provide engine, drive train, tire, and wind noise), a sub-bass sound system (to provide vertical vibration), a computer system to project images of an instrument panel, and other hardware. The projection screen, offering a 30 degree horizontal field of view, was 20 ft (6.1 m) in front of the driver, effectively at optical infinity.

The driving environment depicted consisted of traffic signs, trees, road edge posts, and lead vehicles. Subjects drove on a 20-ft-wide, two-lane, winding road. The road had solid edge delineation and a dashed centerline. Appendix A provides a complete geometric description of the test roads. Figure 3 shows a typical road scene.



Figure 3. Typical road scene with 170 ft headway

The overall arrangement of equipment at the time of the experiment was conducted is shown in Figure 4. A Titmus model OV-7M Vision Tester was used to check visual acuity of the subjects. To avoid excessive boredom and simulate real driving, the subjects listened to self-selected instrumental music (i.e., classical music, jazz) without vocals or a strong beat during the experiment as they normally would while driving.



- 1 1985 Chrysler Laser mockup with simulated hood
- 2 8'X10' projection screen with 3M hi-white encapsulated reflective sheeting
- 3 PMI Motion Technologies ServoDisk DC motor (model 00-01602-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)
- 4 3-spoke steering wheel
- 5 Sharp color LCD projection system (model XG-E850U)
- 6 4"X13" plexiglas screen
- 7 ELO Touch Systems Intellitouch monitor (model E284A-1345)
- 8 Sharp computer projection panel (model QA-1650)
- 9 3M overhead projector (model 9550)
- 10 Kenwood stereo cassette deck (model KX-48C), stereo graphics equalizer (model GE-7030), and AM-FM stereo receiver (model KRA-4080)
- 11 Power Macintosh 9500/200
- 12 Power Macintosh 7100/80AV
- 13 Power Macintosh 8500/120
- 14 Macintosh Quadra 840AV
- 15 Panasonic GP-KS152 "lipstick" Camera
- 16 Alpine MRV-T300 Amplifier
- 17 Aura AST-1B-4 Bass Shakers
- 18 Bernoulli Mac Transporter 230-MB drive
- 19 Dell OptiPlex GXM 5166
- 20 Macintosh Quadra 700
- 21 Video recording system
- 22 Panasonic WV-BP510 low level light camera

Figure 4.
Planview of simulator laboratory

Test Activities and Sequence

Subjects began by completing consent (Appendix B) and biographical forms (Appendix C), and having their vision checked. (See Appendix D for complete instructions.) Then the subject was seated in the driving simulator. After the protocol was described, the subject practiced driving until he/she was comfortable and was familiar with the simulator handling. Then the subject drove for 6 runs of about 6 or 7 minutes in length with two different vehicles to follow in each run. Specifically, the subjects were told to "follow the vehicles as you normally would in real driving." The first vehicle appeared on the road and later pulled off to the side of the road. The second vehicle merged onto the road in view far ahead of the subject and later came to a stop. Data was recorded for each steady-state portion of the following task for each vehicle, headway, speed, and lateral position.

The time history of the lead vehicle followed a script that specified the time when the vehicle was to accelerate or decelerate and to what speed. A copy of the script and the equations of motion that determined the performance of the lead vehicle appear in Appendix E. The values selected were based on recommendations from vehicle dynamics experts in UMTRI's Engineering Research Division. In this experiment, there were two lead vehicle speed conditions: (1) low (mean speed 46 mi/hr (75 km/hr), standard deviation 4.2 mi/hr (6.8 km/hr) and (2) high (mean speed 48 mi/hr (77 km/hr), standard deviation 7.1 mi/hr (11.4 km/hr)). The slight difference in mean speed was a design error. Figures 5 and 6 show the lead vehicle speeds for the two test conditions as a function of time.

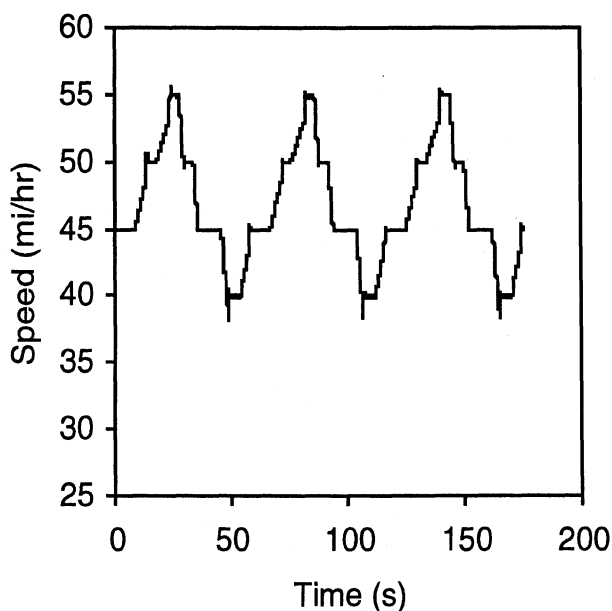


Figure 5. Speed of lead vehicle (low variance)

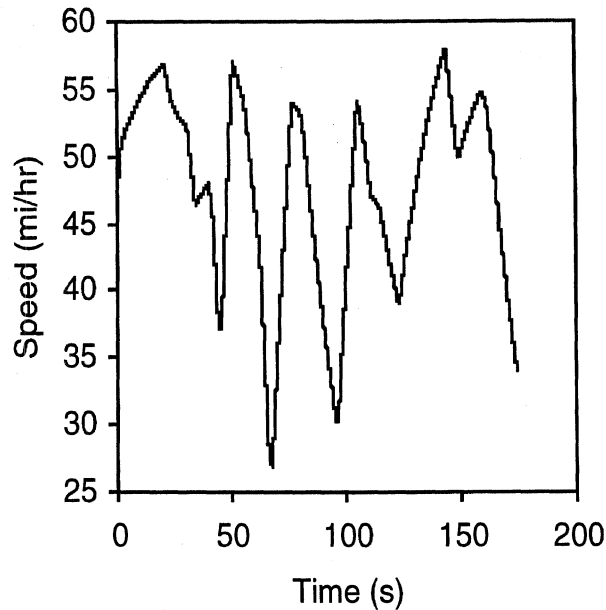


Figure 6. Speed of lead vehicle (high variance)

Table 3 shows how the type of vehicles and their speed variance were partially counterbalanced across runs. The bus and the tractor trailer had low speed variability while the car and the pickup had both low and high speed variability, combinations consistent with their performance capabilities.

Table 3. Vehicles followed for each run

| Subjects | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 |
|----------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 1,9 | <u>C</u> <u>P</u> | T B | C T | <u>P</u> <u>C</u> | C P | P B |
| 2,10 | T C | <u>P</u> <u>C</u> | B P | B T | <u>C</u> <u>P</u> | P C |
| 3,11 | B T | P B | <u>C</u> <u>P</u> | P C | T C | <u>P</u> <u>C</u> |
| 4,12 | <u>P</u> <u>C</u> | C P | B C | <u>C</u> <u>P</u> | T B | P T |
| 5,13 | B C | <u>C</u> <u>P</u> | T P | B C | <u>P</u> <u>C</u> | P T |
| 6,14 | T B | C B | <u>P</u> <u>C</u> | P T | P C | <u>C</u> <u>P</u> |
| 7,15 | <u>C</u> <u>P</u> | T P | C T | <u>P</u> <u>C</u> | B P | C B |
| 8,16 | P T | <u>P</u> <u>C</u> | P B | C B | <u>C</u> <u>P</u> | T C |

Key: C = Car, P = Pickup truck, B = Bus, T = Tractor trailer,
 normal typeface = low speed variation, outlined typeface = high speed variation

Road curvature was intended to be varied in two ways: large and small. However, the student that developed the roads to be used in the simulation did not vary the curvature of the roads. Unfortunately this mistake was not caught until the data was being analyzed, too late to rerun subjects.

As a secondary task, subjects also asked to call out the type of highway sign he/she drove by: "Interstate," "U.S.," or "Michigan" (see Figure 7). The secondary task was

added so that the subject would not be totally focused on the lead vehicle, just as in real driving.

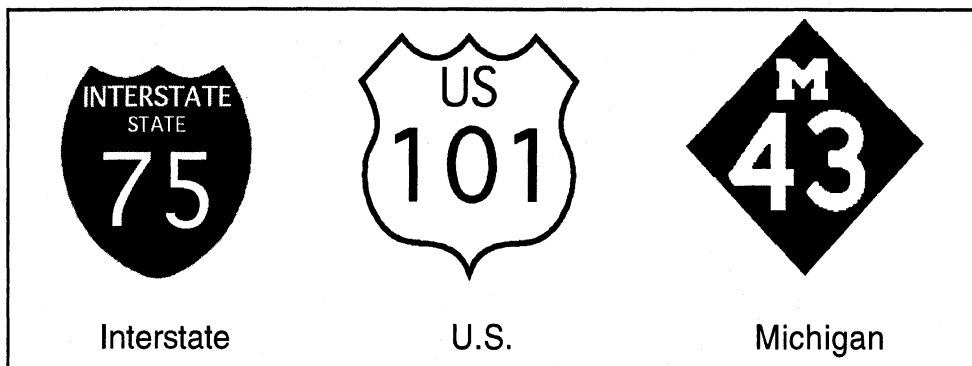


Figure 7. Road signs that subjects identified while driving

After the subject had completed all test runs, subjects rated how much each type of vehicle blocked their vision, ranked the following distances, and rated the fidelity of the simulator on several dimensions (Appendix F).

RESULTS

Data Analysis Methods and ANOVA Approach

The test data was taken from two 11,430 ft (347 m) segments from one steady-state drive which contained two vehicle-following tasks (separated by a break). Vehicle parameters including headway distance were sampled at a maximum of 30 Hz when the lead vehicle was far away, to a minimum of 12 Hz when the lead vehicle was closer. For the most part, data was collected approximately at 18 to 24 Hz. There were approximately 768,000 sampling periods in the entire data set. These periods began just after the lead vehicle merged onto the road and ended just before the lead vehicle pulled off the road. These periods should represent steady state driving.

The simulator only collected headway data up to 600 ft (183 m, the maximum sight distance). Drivers were not told per se to stay within the sight distance of the lead vehicle. In fact, many of the older drivers did not want to see the lead vehicle, and lagged behind so it would not be in sight (Table 4). Therefore, all headway values exceeding 600 ft were capped at 600 ft, skewing the data. Various alternatives were explored to estimate the headway distance in those cases (e.g., extrapolating from when vehicles were in sight), however such procedures proved to be cumbersome and based on tenuous assumptions. The capped values created smaller differences resulting in conservative conclusions.

Table 4. Percentage of runs with headway beyond 600 ft (183 m)

| Age and Gender Group | Runs where headway exceeded 600 ft | Percent (out of 48 runs) |
|----------------------|------------------------------------|--------------------------|
| young women (n=4) | 15 | 31.3 |
| old women (n=4) | 33 | 68.8 |
| young men (n=4) | 4 | 8.3 |
| old men (n=4) | 38 | 79.2 |

Note: In each 4 subject age group there were 6 blocks of trials/subject or 48 total.

Headway values could have been constrained by instructing the subjects to drive with the lead vehicle in view. However, that instruction was inconsistent with the study intent, to determine how people naturally drive. Another alternative would be to increase the sight distance, a potential computational overload for the simulator. For future studies, tracking the range of out of sight vehicles is being considered. In fact, as the data will show, some of the older drivers felt more comfortable driving when there was no lead vehicle in view. As a footnote, there were no mirrors in the simulator and no vehicles following the test vehicle, so pressure to keep up with traffic was less than in real driving, a major weakness of this experiment.

The data were examined using Analysis of Variance (ANOVA). (See Appendix G.) The main effects were (1) driver age (young, old), (2) driver sex (men, women), (3) subject nested within age and sex, (4) vehicle (car, pickup truck, tractor trailer, bus), (5) speed variance (low, high), (6) block (6 levels) and (7) run (2 levels). Only block and run were treated as continuous. The model used included those seven main effects,

plus five interactions (age * vehicle, age * variance, age * sex, sex * vehicle, and the age * sex * vehicle combination). The rationale for this choice is that sex and age often interact with other characteristics, and it was important to explore those interactions with other factors of interest. Also, given the interest in vehicle differences, vehicle interactions were included. All other interactions were pooled into the residual error term.

An alternative approach explored was to consider the data piecemeal, analyzing the car and pickup truck at two levels of speed variance in one model, and to consider all four vehicles at low variance in another model. This approach proved to be very complicated and confusing when explained. An alternative approach would have been to treat the vehicle-variance combination as a 6-level factor, and explore variance effects in post-hoc tests. As the data results will show, speed variance did not have a significant effect, so separating it in this manner would have been considerable additional work with no demonstrable benefit.

To simplify the analysis, the mean values for each subject for each run (192 total data points for each dependent measure) served as the unit of analysis. Again, headways in excess of 600 ft (183 m) were assumed to be 600 ft. The measures explored included mean headway, headway variance, lateral position, and lateral position variance. Although other measures were collected (e.g., speed, yaw angle), there was no reason they should be affected by the lead vehicle and were not explored.

What Affects Following Distance?

Following distance was significantly affected by all individual differences (age, sex, age* sex, subjects nested within sex), all at the $p < 0.0001$ level. (See Appendix G for the ANOVA tables.) The mean distance was 286 ft (87 m) for younger drivers and 473 ft (144 m) for older drivers, 65 percent greater. Since the speeds driven for all conditions were essentially identical, this also represents a 65 percent difference in time headway. Had the sight distance not been capped for older drivers, their following distance would have been much greater. The age*sex interaction is shown in Figure 8. Notice younger men followed most closely (221 ft [67 m]), reflecting their aggressiveness, but old men maintained the greatest following distance (491 ft [150 m]), reflecting their diminished capabilities.

Differences between individuals were substantial with the estimated following distances varying from 134 to 490 ft (41 to 149 m). For the 490 ft case, the actual value was probably much greater given that values only up to 600 ft were recorded. At the 45 mi/hr mean speed of the lead vehicle, these distances correspond to headway times of 2.0 to 7.4 s, times that are far larger than are reported for on-the-road studies (Table 1).

The impact of these characteristics is most clearly shown in the histograms of following distance (Figure 9). To emphasize differences in the shape of the distributions, the vertical axes have been truncated.

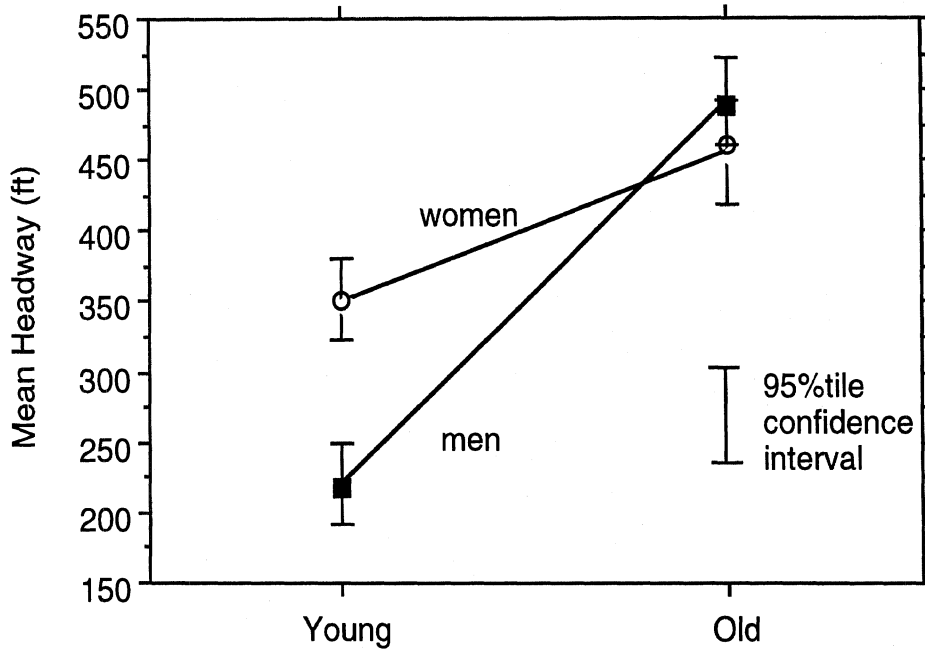
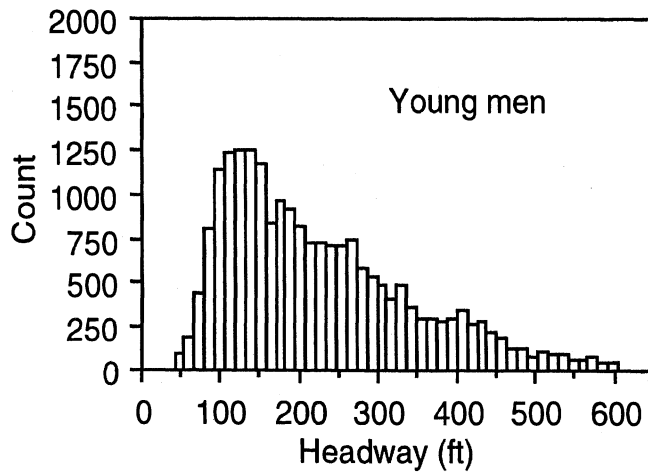
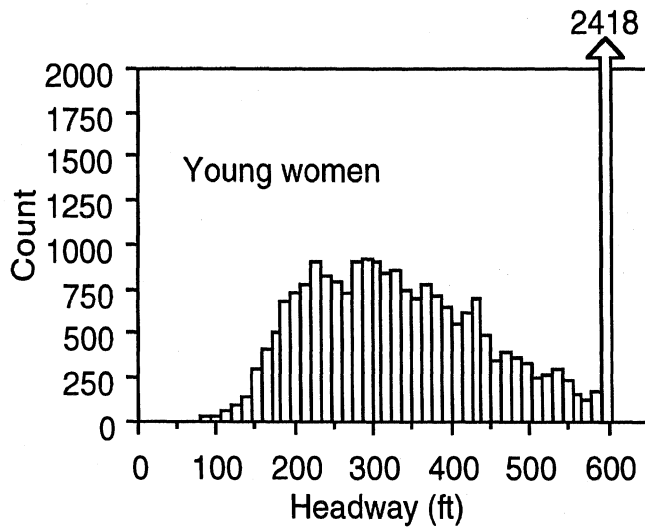


Figure 8. Sex * age interaction and headway



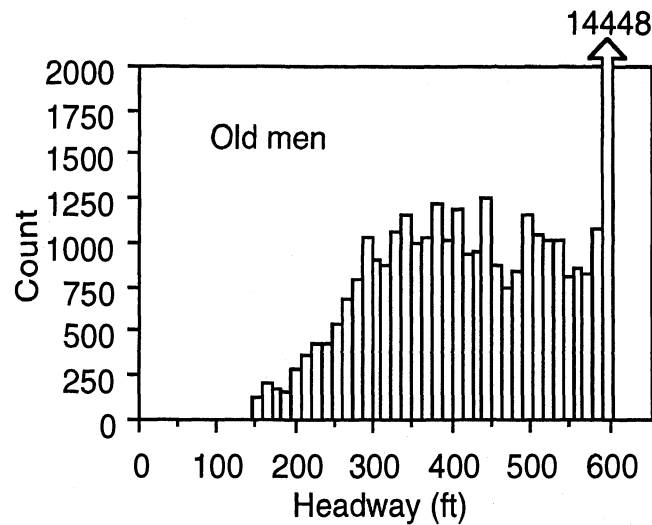
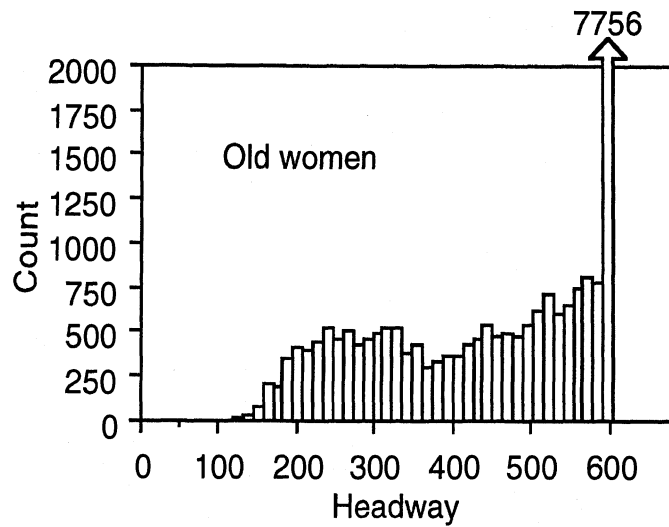


Figure 9. Histograms for headway distance as a function of age and sex

The effect of vehicle type was significant ($p=.01$) but variance and all other factors were not. Figure 10 shows those effects. The main difference is that drivers followed the car a bit closer (359 ft [109 m]) than the pickup (392 ft [119 m]), bus (386 ft [118 m]), or large truck (392 ft [119 m]). Thus, although vehicle size does have some influence on following distance, the effect does not occur for all vehicles.

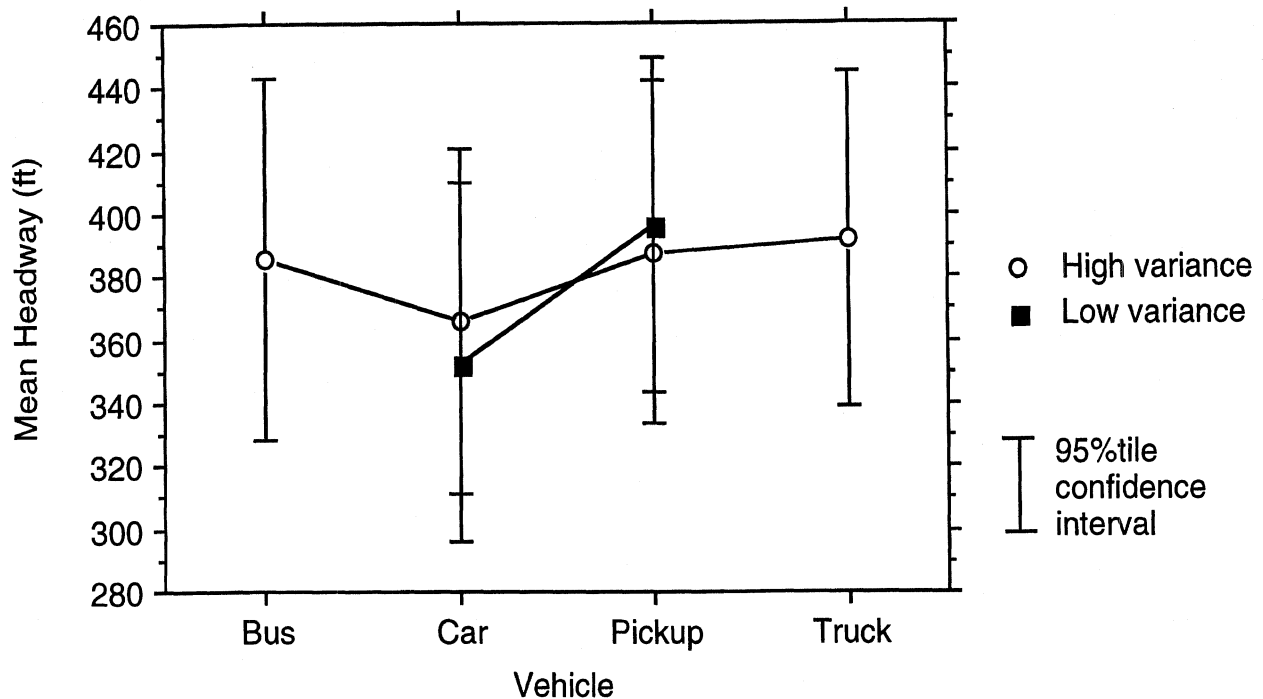


Figure 10. Following distances as a function of lead vehicle type

What Affects Following Distance Variability?

In a manner similar to the mean following distance, the standard deviation of headway distance was significantly affected by driver age ($p=0.02$), driver sex ($p<0.0001$), the age by sex interaction ($p=0.02$), and subject ($p<0.0001$). However, no other factors were significant. Figure 11 shows the standard deviation data for the age * sex interaction. For individual subjects, headway standard deviations ranged from 18 to 93 ft (5 to 28 m). Seven of the 16 subjects were in the 50 to 80 ft (15 to 24 m) range.

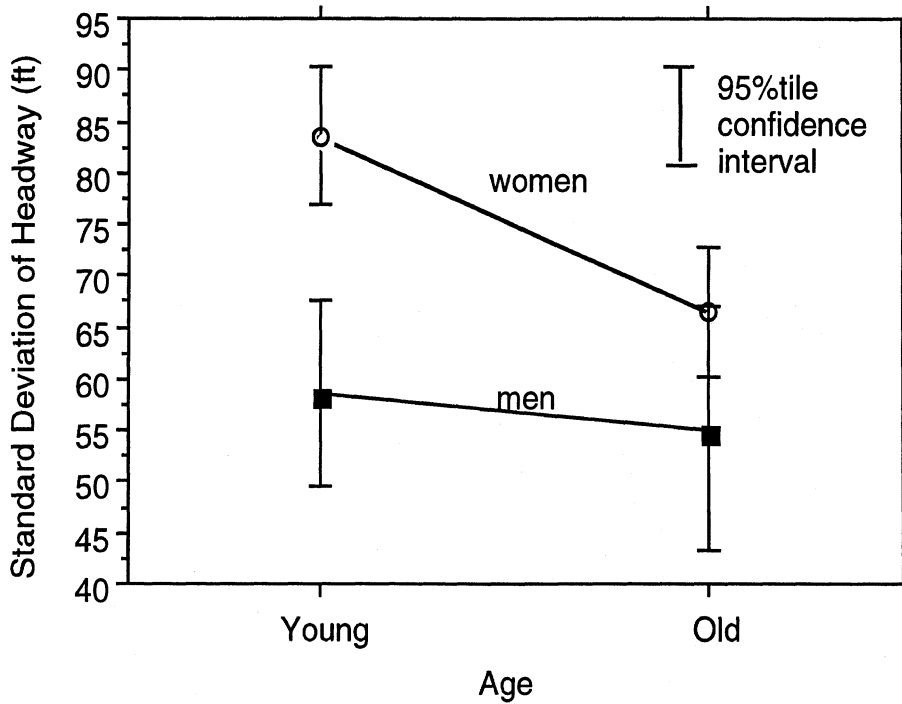


Figure 11. Age by sex interaction for headway variability

Figure 12 shows the headway variability data as a function of vehicle type and lead vehicle speed variance. (Confidence intervals have been omitted for clarity.) There is no explanation why the headway variance when following the car and pickup truck were less when their speed were greater other than chance variation. The differences are quite small (less than 1 mi/hr (1.6 km/hr) in one case, 4 mi/hr in the second).

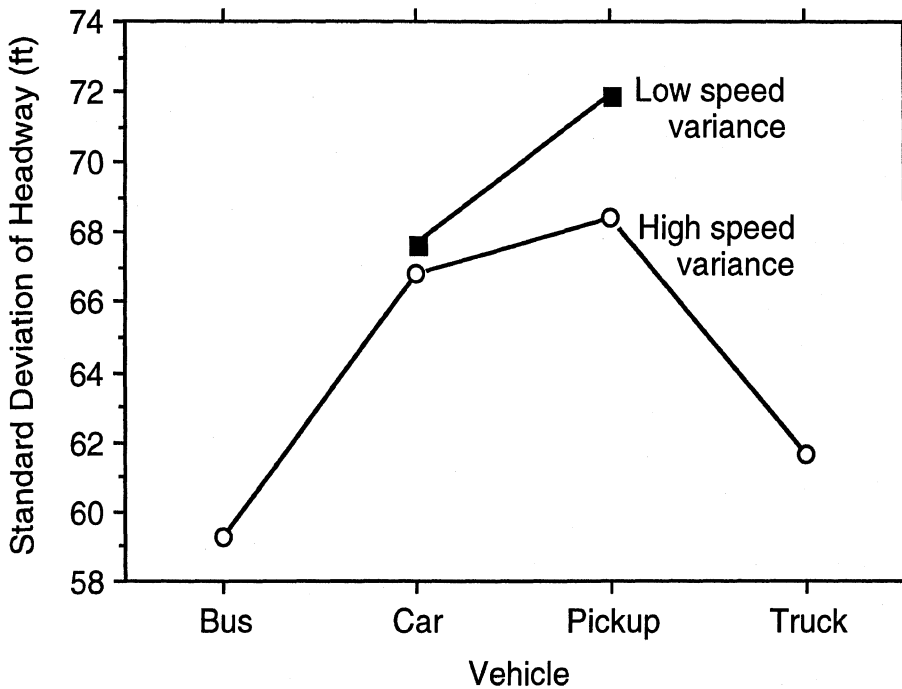


Figure 12. Effect of lead vehicle type and speed variance on headway variability

What Affects Mean Lateral Position?

The pronounced individual differences and need to see around a lead vehicle suggest lane placement might be affected by the lead vehicle type, although the large following distances reported should minimize blockage. In this case, only age, the age by sex interaction, and subject ($p < .0001$) were significant. Figure 13 shows the interaction. The primary difference is that older women drove farther from the centerline (by 0.7 ft [0.2 m]) than young women. Subject means ranged from 5.3 to 6.8 ft (1.6 to 2.1 m) to the right of the centerline.

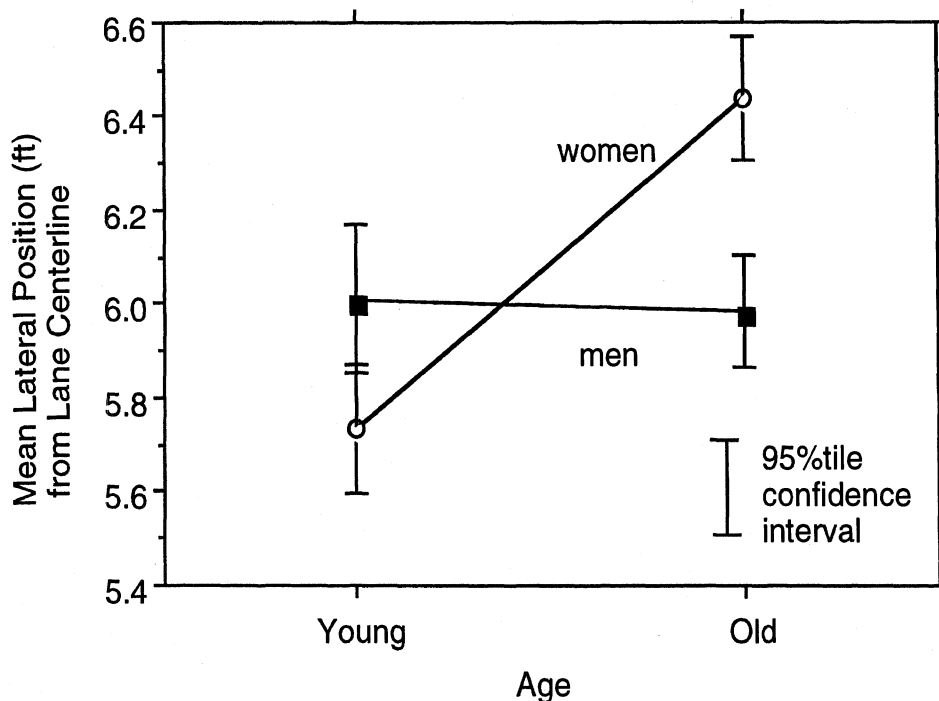


Figure 13. Effect of age and sex on mean lateral position

Vehicle differences were absent, with the means for all 4 vehicle types differing by less than 0.075 ft (.023 m), less than 1 inch.

What Affects the Standard Deviation of Lateral Position?

One might speculate that the size of the lead vehicle might affect how drivers would follow such a vehicle. For example, the larger the vehicle, the greater the concern for maintaining a safe following distance (with less attention devoted to maintaining lane position). In fact, the standard deviation of lane position was affected only by sex, the age by sex interaction, and subjects nested within age and sex. Figure 14 shows the sex by age interaction. Standard deviations ranged from 0.41 to 1.18 ft (0.13 to 0.36 m). In general, young men were best at staying centered in the lane and young women had the poorest performance. Normally, in these situations, the performance of older men would be poorest, but there were only four subjects in each age-sex group.

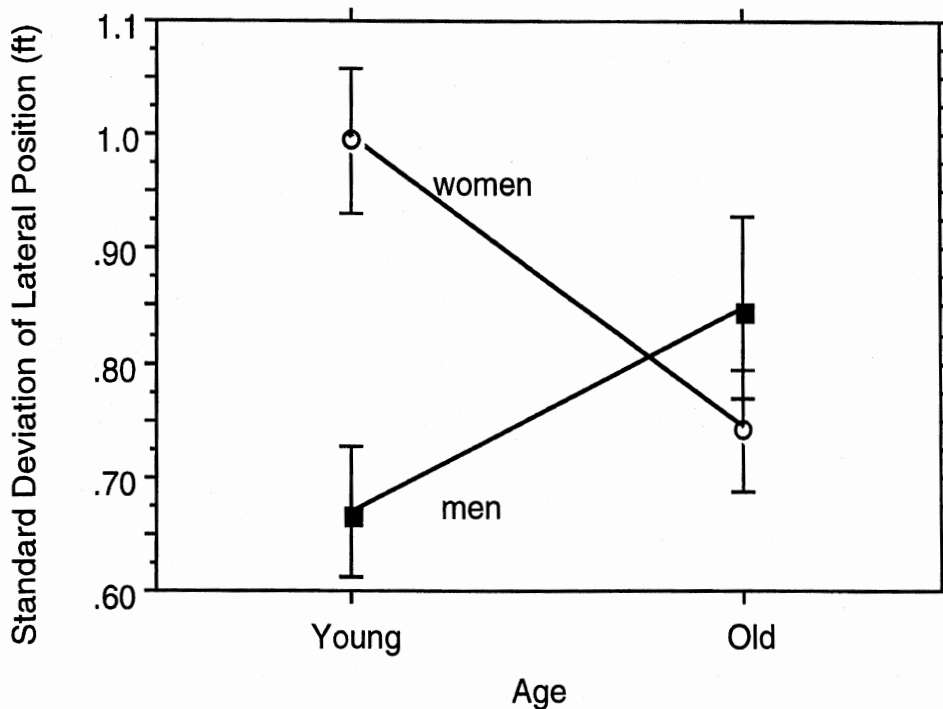


Figure 14. Effect of age and sex on standard deviation of lateral position

Vehicle differences were nonexistent, with the standard deviation of lateral position ranging from 0.79 ft (0.24 m) for the bus to 0.83 ft (0.25 m) for the car.

Subjective Evaluation of the Simulation

Subjects rated the realism of various aspects of the simulator. The overall mean responses are found in Table 5. Most of the ratings fall between 4 and 5, indicating that the subjects did not find the simulation too artificial or too realistic. There were no noticeable differences between age or gender groups. Efforts to improve the scene fidelity are in progress.

Table 5. Subjective rating of simulator realism
(1 to 7 scale, with 1 = very artificial and 7 = very real)

| System | Scale | Rating |
|-------------|----------------------------|--------|
| steering | effort required to operate | 4.5 |
| | response time | 4.9 |
| accelerator | effort required to operate | 4.1 |
| | response time | 4.3 |
| brakes | effort required to operate | 5.4 |
| | response time | 5.4 |
| graphics | road scene | 4.0 |
| | road signs | 4.4 |
| | lead vehicles | 4.1 |
| sound | loudness | 4.7 |
| | pitch/tone | 4.4 |
| vibration | intensity | 4.7 |
| | frequency | 4.6 |

In contrast to the general trends of the data, subjects believed that they followed vehicles at a farther distance proportional to the size of the vehicle. Table 6 shows that the vehicle ranking for the amount of vision blockage (ranked 1 to 4) was identical to the ranking (1 to 4) for the following distance that they thought they preferred for each vehicle.

Table 6. Subjective ranking of vehicle size and preferred headway

| Vehicle | Vision Blocked | Following Distance |
|-----------------|----------------|--------------------|
| Tractor trailer | 1.2 | 3.2 |
| Bus | 2.0 | 3.1 |
| Pickup truck | 3.0 | 2.1 |
| Car | 3.6 | 1.3 |

The subjects were also asked what affects their following distances during real driving. Table 7 lists responses from that evaluation survey. Interestingly, visibility around the vehicle was the most commonly offered reason, even though the following distances were great and there was no oncoming traffic.

Table 7. Subjects' comments on what affects their following distances

| # of times mentioned | Comment |
|----------------------|--|
| 8 | visibility around lead vehicle |
| 7 | behavior of lead vehicle - speed, accelerations, erratic |
| 6 | speed |
| 3 | size |
| 2 | type of car |
| 2 | road type - curves vs. straight portions |
| 1 | smell |
| 1 | type of load |
| 1 | "vision - slower on curves" |
| 1 | avoid tailgating |
| 1 | weather |
| 1 | amount of traffic |

Finally, as a reminder, subjects were asked to identify signs when they appeared to avoid excessive fixation on the lead vehicle. Subjects did quite well on this task, successfully identifying 1141 of 1152 signs (99% success rate). Ten signs were missed, and one was incorrectly identified.

CONCLUSIONS

What Affects Following Distance and Its Variability?

Following distance and its variability were primarily affected by individual differences, though following distances were less when following a car than other vehicles (by about 30 ft, a 10% difference). Lead vehicle speed variance (for the 2 values examined) had no influence on following distance. Following distances were 65% greater for older subjects than young subjects (473 vs. 286 ft, 144 vs. 87 m). Headway variance (for 45 mi/hr [72 km/hr]) ranged from 18 to 93 ft (5 to 28 m). The extremes of the following distances were young men (closest) and old men (farthest). In this experiment older subjects often did not want to see the lead vehicle, so they often followed in excess of the maximum sight distance in the simulator (600 ft [183 m]). These values are several times larger than are reported in the literature for driving in traffic.

What Affects the Lateral Position and Lateral Variability of a Following Vehicle?

Lateral position and lane variability were not expected to be affected by the nature of the lead vehicle, and that proved to be the case. These dependent measures were primarily influenced by subject age, the age by sex interaction, and subject with age-sex category differences. Subject standard deviations ranged from 0.41 to 1.18 ft (0.13 to 0.36 m).

What Are Important Considerations in Simulator-Based Following Studies?

It appears likely that limitations of the simulator and experiment design may have affected the results of this study. In order of their likely importance these include (1) the lack of following traffic, (2) constraints on the maximum sight distance, (3) update problems associated with close following, and (4) lead vehicle image bitmap jitter.

Since there were no mirrors in the simulator, the pressure to keep up with traffic (due to a vehicle following the subject) was not present. The stress imposed by being closely followed can be considerable. In the context of the UMTRI simulator, adding a mirror-based rear vision system would be a challenge given the laboratory size, though LCD displays simulating mirrors is a possibility.

Subjects were instructed to "follow the vehicles as you normally would in real driving." As a consequence, some subjects did not want to see the lead vehicle, and sometimes followed at a distance beyond the cutting plane of the scene generator (the maximum sight distance), here set to 600 ft (183 m). When the maximum was exceeded, the headway was assumed to be 600 ft. Had a larger maximum distance been used, the mean headways would have proved to be larger. To avoid overloading the simulator processor, there might be benefit in extending the cutting plane distance for the lead vehicle, but not the road scene in future studies.

Simulator update problems may also have encouraged subjects to follow at greater than normal distances. When driving close to a lead vehicle, the image was noticeably pixelated from enlargement of the scanned image bitmap of the vehicle. Also, when driving close, updating the image bitmap of the lead vehicle decreased the update rate of the simulator, making it less responsive and comfortable to drive.

Finally, when closely following a lead vehicle, the change in the angular aspect was greater as the subject shifted their position laterally within the lane. This caused the bit map of the lead vehicle to change, and in some situations the image of the lead vehicle to jitter as the bitmap alternated between two choices. Increasing headway eliminated this annoying jitter. Since this experiment, some changes have been made to the software to change the thresholds for swapping bitmaps.

Closing Comment

For the conditions examined, the size and speed variance of the lead vehicle had little influence on following behavior. However, this lack of differences may be a consequence of the larger than normal following distances observed, distances influenced by the simulator characteristics. These data contain hints that there are significant limitations to using the UMTRI simulator without modification for vehicle-following studies. Some of these problems are readily resolved and steps to complete them are in process.

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APPENDIX A - DESCRIPTION OF ROADS

Road 1

| Length (ft) | Curve Type | Curvature (ft) |
|-------------|------------|----------------|
| 900 | Right | 10000 |
| 600 | Straight | 0 |
| 480 | Left | 11000 |
| 840 | Right | 9500 |
| 480 | Straight | 0 |
| 990 | Left | 13000 |
| 990 | Straight | 0 |
| 930 | Left | 9500 |
| 1260 | Straight | 0 |
| 1140 | Right | 12000 |
| 600 | Straight | 0 |
| 1170 | Left | 10000 |
| 630 | Right | 11000 |
| 450 | Straight | 0 |

Road 3

| Length (ft) | Curve Type | Curvature (ft) |
|-------------|------------|----------------|
| 450 | Straight | 0 |
| 630 | Left | 11000 |
| 1170 | Right | 10000 |
| 600 | Straight | 0 |
| 1140 | Left | 12000 |
| 1260 | Straight | 0 |
| 930 | Right | 9500 |
| 990 | Straight | 0 |
| 990 | Right | 13000 |
| 480 | Straight | 0 |
| 840 | Left | 9500 |
| 480 | Right | 11000 |
| 600 | Straight | 0 |
| 900 | Left | 10000 |

Road 2

| Length (ft) | Curve Type | Curvature (ft) |
|-------------|------------|----------------|
| 900 | Left | 10000 |
| 600 | Straight | 0 |
| 480 | Right | 11000 |
| 840 | Left | 9500 |
| 480 | Straight | 0 |
| 990 | Right | 13000 |
| 990 | Straight | 0 |
| 930 | Right | 9500 |
| 1260 | Straight | 0 |
| 1140 | Left | 12000 |
| 600 | Straight | 0 |
| 1170 | Right | 10000 |
| 630 | Left | 11000 |
| 450 | Straight | 0 |

Road 4

| Length (ft) | Curve Type | Curvature (ft) |
|-------------|------------|----------------|
| 450 | Straight | 0 |
| 630 | Right | 11000 |
| 1170 | Left | 10000 |
| 600 | Straight | 0 |
| 1140 | Right | 12000 |
| 1260 | Straight | 0 |
| 930 | Left | 9500 |
| 990 | Straight | 0 |
| 990 | Left | 13000 |
| 480 | Straight | 0 |
| 840 | Right | 9500 |
| 480 | Left | 11000 |
| 600 | Straight | 0 |
| 900 | Right | 10000 |

APPENDIX B - CONSENT FORM

Subject: _____

Date: _____

Vehicle Following Study

Participant Consent Form

University of Michigan Transportation Research Institute
Human Factors Division

The purpose of this experiment is to investigate how the following distances and lane positions of passenger cars vary as a function of the size of the lead vehicle, variations in its speed, presentation of road signs and road curvature. During the experiment, you will drive a simulator and will simply drive behind various vehicles for several minutes at a time while taking notice of highway signs.

The entire study will take approximately 1 hour and 40 minutes to complete. You will be paid \$20 for your participation. A few drivers experience motion discomfort while operating the simulator. Should you feel uncomfortable at any time and for any reason, you may stop the experiment. You will be paid regardless.

Thank you for your help with our study. If you have any questions, please do not hesitate to ask the experimenter at any time.

The sessions will be videotaped. Do you object to being videotaped?

Yes

No

I have reviewed and understand the information presented above. My participation in this study is entirely voluntary.

Subject Signature

Date

Subject Name (PRINTED)

Witness

Investigator: Paul Green

APPENDIX C - BIOGRAPHICAL FORM

Subject: _____

Date: _____

University of Michigan Transportation Research Institute
Human Factors Division
Following Behavior Biographical Form

General Information

Name: _____

Sex (circle one): Male Female Age: _____

Occupation: _____

(If retired, please note your former occupation. If student, note your major)

Driving Experience

Are you a licensed driver (circle one)? Yes No

How many years have you been driving? _____

What kind of car do you drive the most?

Year: _____ Make: _____ Model: _____

Approximate annual mileage: _____

Simulator Experience

Have you ever driven the UMTRI driving simulator? Yes No

How susceptible are you to motion sickness (circle one)?

Never Rarely Sometimes Often Don't Know

Driving Behavior

How aggressive a driver do you consider yourself be?

1 2 3 4 5 6 7 8 9
least aggressive most aggressive

Suppose there are three lanes on an expressway. In which lane would you drive most often?

Left Lane Center Lane Right Lane

Have you ever been in a collision when you rear-ended another vehicle?

Yes No

If yes, describe:

Have you ever been stopped for speeding over the last 3 years?

Yes No

If Yes, how many times? _____

How many speeding tickets did you receive? _____

| TITMUS VISION: (Landolt Rings) | | | | | | | | | | | | | | Corrective lenses worn? |
|--------------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | |
| T | R | R | L | T | B | L | R | L | B | R | B | T | R | |
| 20/200 | 20/100 | 20/70 | 20/50 | 20/40 | 20/35 | 20/30 | 20/25 | 20/22 | 20/20 | 20/18 | 20/17 | 20/15 | 20/13 | Yes / No |

APPENDIX D - EXPERIMENT INSTRUCTIONS

Experiment Instructions

Driver Behavior While Following Trucks and Buses
Great Lakes Center for Truck and Transit Research
University of Michigan Transportation Research Institute

Before Subject Arrives

Check

- sound
- projector
- load practice runs
- change headway to **600 ft.**
- bass shaker

Make sure you have:

- participant consent forms
- biographical form
- post test evaluation form
- payment form and money
- experiment order

Test Subject's Vision

"Please put on contacts or glasses if you use them when you drive."

Turn on both eye switches on the vision tester. Adjust the height of the vision tester for the subject. Make sure subject wears any vision correction that is worn while driving. Note on the biographical form if corrective lenses were worn.

"Can you see in the first diamond that the top circle is complete but the other three are incomplete? In each diamond, tell me the location of the complete circle - top, left, right, or bottom."

Prompt the subject until s/he has missed two in a row. Record the last number answered correctly on the bottom of the biographical form.

Stop test when 2 consecutive incorrect answers are given. Take the last correct answer to be the subject's visual acuity.

Introduction

Seat Subject in car and sit in front of subject

- **Purpose:** "The purpose of this experiment is to investigate how your highway following behavior while driving is affected by changing driving conditions."
- **Primary Task:** "Your primary task will be to drive along a typical highway road while following a vehicle."
- **Secondary Task:** "In addition, you will have a secondary task to verbally note any highway signs you may see."
- **Time:** "The entire experiment will take approximately 1 hour and 40 minutes."
- **Pay:** "You will be paid \$20. You can stop anytime if you feel any discomfort. You will be paid regardless."

Hand out Consent and Biographical form

"There are a few forms that we need to complete before we can begin."

- **Consent Form:** "Please read and sign the consent form. It basically repeats the information that I just told you."
- **Biographical Form:** "This is the biographical form. It just asks for some general information about yourself."
- **Music Selection:** "You will be listening to music as you drive. Please select a CD." (present subject with CDs)
- **Questions?:** "If you have any questions, please feel free to ask at any time."

Introduce subject to simulator features

- **Seat Adjust:** "There are seat controls located on the floor on your left."
- **Steering Adjust:** "You can adjust the steering wheel by pulling on this lever."
- **Torque Motor Warning:** "The steering system will feel very much like a real car, so simply drive as you would a real car."
- **Brakes and Accelerator:** "The brake and the accelerator are both fully functional."
- **Seat Belt:** "Please wear your seat belt. The simulator will vibrate but will not move."

Experiment Procedures

Introduce to the format of the experiment

- "There will be 6 driving sessions of about 6 or 7 minutes each with short breaks in between."
- "In each session, you will have 2 different vehicles to follow."
- "Don't pass any vehicles, but you may go by a vehicle when it is going off the road."
- "You will be driving along a two lane highway. Remain in the right lane at all times."
- "Drive at or below the posted speed limit: 55 mph."
- Show Signs "When you see one of these three signs, say 'Interstate,' 'Michigan,' or 'US,' corresponding to the type of sign **as soon as you recognize them**. You will not need to announce speed limit signs."
- **"With the exception of no passing, follow the vehicles as you normally would in real driving. Please watch your speed and remember to call out the highway signs."**

Begin the Practice Run

"To get you used to the simulator, you will now practice driving."

- During the practice run, show the subject feedback of the simulator: "Now I will have you perform some maneuvers to familiarize you with the vehicle behavior and audio feedback. Put your left tire over the centerline. Can you feel the bumps of the centerline? Now put your vehicle in the left lane of the road. The beeping means that you are on the wrong side of the road. It does not mean there is a car beeping at you. Now put your right tires on the right shoulder of the road. Can you feel the gravel?"
- **"With the exception of no passing, follow the vehicles as you normally would in real driving. Please watch your speed and remember to call out the highway signs."**

Begin the real run

- Don't forget to:**
- 1) Start the music
 - 2) To show elapsed time on traffic computer
 - 3) Collect data for subject
 - 4) Collect data for lead vehicles
 - 5) Write down the times of responses

"Now we can begin the experiment."

- **"With the exception of no passing, follow the vehicles as you normally would in real driving. Please watch your speed and remember to call out the highway signs."**

APPENDIX E - LEAD VEHICLE DYNAMICS

Script for Speed - Low Variance Condition

#truck limitations (values that follow are vehicle image identifiers)

#401 Bus3b.multiLib
#402 mercedes5b.multiLib
#403 PickUp2b.multiLib
#404 Trailer2b.multiLib

#####

#####lead vehicle merges

set picture 402
set location 1 34
set target speed 0
set speed 0
set ypos 12

set target ypos 5
set target speed 45

set accel 5
after time 20
set accel 6
after time 10
set accel 7
after time 11
set accel 0

#####

#####data collection on lead 1

after location 2 20

##accel from 45 to 50 in 5 seconds

set accel 7
after time 5
set accel 0
set target speed 50

after time 4

##accel from 50 to 55 in 6 seconds

set accel 7
after time 6
set accel 0
set target speed 55

after time 4

##brake from 55 to 50 in 2 seconds

set brake 5
after time 2
set brake 0
set target speed 50

after time 4

##brake from 50 to 45 in 2 seconds

set brake 5
after time 2
set brake 0
set target speed 45

after time 10

##brake from 45 to 40 in 2.5 seconds

set brake 5
after time 3
set brake 0
set target speed 40

after time 5

##accel from 40 to 45 in 4 seconds

set accel 7
after time 4
set accel 0
set target speed 45

after time 9

##accel from 45 to 50 in 5 seconds

set accel 7
after time 5
set accel 0
set target speed 50

after time 4

##accel from 50 to 55 in 6 seconds

set accel 7
after time 6
set accel 0
set target speed 55

after time 4

##brake from 55 to 50 in 2 seconds

set brake 5
after time 2
set brake 0
set target speed 50

after time 4

##brake from 50 to 45 in 2 seconds

set brake 5
after time 2
set brake 0
set target speed 45

after time 10

##brake from 45 to 40 in 2.5 seconds

set brake 5
after time 3
set brake 0
set target speed 40

after time 5

##accel from 40 to 45 in 4 seconds

set accel 7
after time 4
set accel 0
set target speed 45

after time 9

##accel from 45 to 50 in 5 seconds

set accel 7
after time 5
set accel 0
set target speed 50

after time 4

##accel from 50 to 55 in 6 seconds

set accel 7
after time 6
set accel 0
set target speed 55

after time 4

##brake from 55 to 50 in 2 seconds

```
set brake 5
after time 2
set brake 0
set target speed 50
```

```
after time 4
```

```
##brake from 50 to 45 in 2 seconds
```

```
set brake 5
after time 2
set brake 0
set target speed 45
```

```
after time 10
```

```
##brake from 45 to 40 in 2.5 seconds
```

```
set brake 5
after time 3
set brake 0
set target speed 40
```

```
after time 5
```

```
##accel from 40 to 45 in 4 seconds
```

```
set accel 7
after time 4
set accel 0
set target speed 45
```

```
#####
```

```
#####lead vehicle leaves
```

```
after location 3 1
set target speed 0
set brake 4
```

Script for Speed - High Variance Condition

```
# first real pilot, truck limitations
```

```
#401 Bus3b.multiLib
```

```
#402 mercedes5b.multiLib
```

```
#403 Pickup2b.multiLib
```

```
#404 Trailer2b.multiLib
```

```
#####
```

```
#####lead vehicle merges
```

```
set picture 403
set location 1 34
set target speed 0
```

set speed 0
set ypos 12

set target ypos 5
set target speed 45

set accel 5
after time 20
set accel 6
after time 10
set accel 7
after time 11
set accel 0

#####data collection on lead 1

after location 2 20

##accel from 45 to 50 in 5 seconds
set accel 7
after time 5
set accel 0
set target speed 50

after time 8

##accel from 50 to 55 in 6 seconds
set accel 7
after time 6
set accel 0
set target speed 55

after time 8

##brake from 55 to 50 in 2 seconds
set brake 5
after time 2
set brake 0
set target speed 50

after time 9

##brake from 50 to 45 in 2 seconds
set brake 5
after time 2
set brake 0
set target speed 45

after time 20

##brake from 45 to 40 in 2.5 seconds

set brake 5
after time 3
set brake 0
set target speed 40

after time 7

##accel from 40 to 45 in 4 seconds

set accel 7
after time 4
set accel 0
set target speed 45

after time 15

##accel from 45 to 50 in 5 seconds

set accel 7
after time 5
set accel 0
set target speed 50

after time 8

##accel from 50 to 55 in 6 seconds

set accel 7
after time 6
set accel 0
set target speed 55

after time 8

##brake from 55 to 50 in 2 seconds

set brake 5
after time 2
set brake 0
set target speed 50

after time 9

##brake from 50 to 45 in 2 seconds

set brake 5
after time 2
set brake 0
set target speed 45

after time 20

##brake from 45 to 40 in 2.5 seconds

set brake 5
after time 3
set brake 0
set target speed 40

after time 7

##accel from 40 to 45 in 4 seconds

set accel 7
after time 4
set accel 0
set target speed 45

#####

#####lead vehicle leaves

after location 3 1
set target speed 0
set brake 4

after location 3 12
set target ypos 20

Vehicle Acceleration Equations

Acceleration is computed as:

$$\text{Acceleration} = (\text{TractiveForce} - \text{BrakeForce} - \text{RollingResistance} - \text{AscentResistance} - \text{AccelerationResistance} - \text{AerodynamicResistance}) / (\text{VehicleMass} * 1.6)$$

$$\text{Speed} = \text{Speed} + \text{Acceleration} * \text{UpdateInterval}$$

where the UpdateInterval is usually 1/30th of a second.

The equations for the values used to compute acceleration are as follows:

$$\text{TractiveForce} = \text{AcceleratorPercent} * \text{AcceleratorCoefficient}$$

TractiveForce is the force exerted by the drive wheels.

AcceleratorPercent is the percent application of the accelerator pedal.

AcceleratorCoefficient is a constant.

$$\text{BrakeForce} = \text{BrakePercent} * \text{BrakeCoefficient}$$

BrakeForce is the force exerted by the brakes. BrakePercent is the percent application of the brake pedal. BrakeCoefficient is a constant.

$\text{RollingResistance} = \text{VehicleWeight} * \cos(\text{VehiclePitch}) * \text{RollingCoefficient}$

RollingResistance is the result of friction.

VehicleWeight is the weight of the vehicle.

VehiclePitch is the vehicle's pitch angle.

RollingCoefficient is a constant.

$\text{AscentResistance} = \text{VehicleWeight} * \sin(\text{VehiclePitch})$

AscentResistance is the force of gravity due climbing or descending hills.

$\text{AccelerationResistance} = \text{VehicleMass} * \text{Acceleration} * 1.3$

AccelerationResistance is the result of the vehicle's inertia.

VehicleMass is the mass of the vehicle.

$\text{AerodynamicResistance} = \text{RelativeSpeed} * \text{RelativeSpeed} * \text{DragCoefficient}$

AerodynamicResistance is aerodynamic drag.

RelativeSpeed is Speed plus WindSpeed.

WindSpeed is the sum of three sine waves and is intended to model variable wind speed/direction.

DragCoefficient is a constant.

The default values for the various constants have changed over time and their exact values are not available. In general, TractiveForce, BrakeForce (when brakes were used) and AerodynamicResistance are the dominant forces. AscentResistance is of no consequence if there are no hills (as was the case). RollingResistance is a constant. AccelerationResistance is only important at low speeds or during fast acceleration.

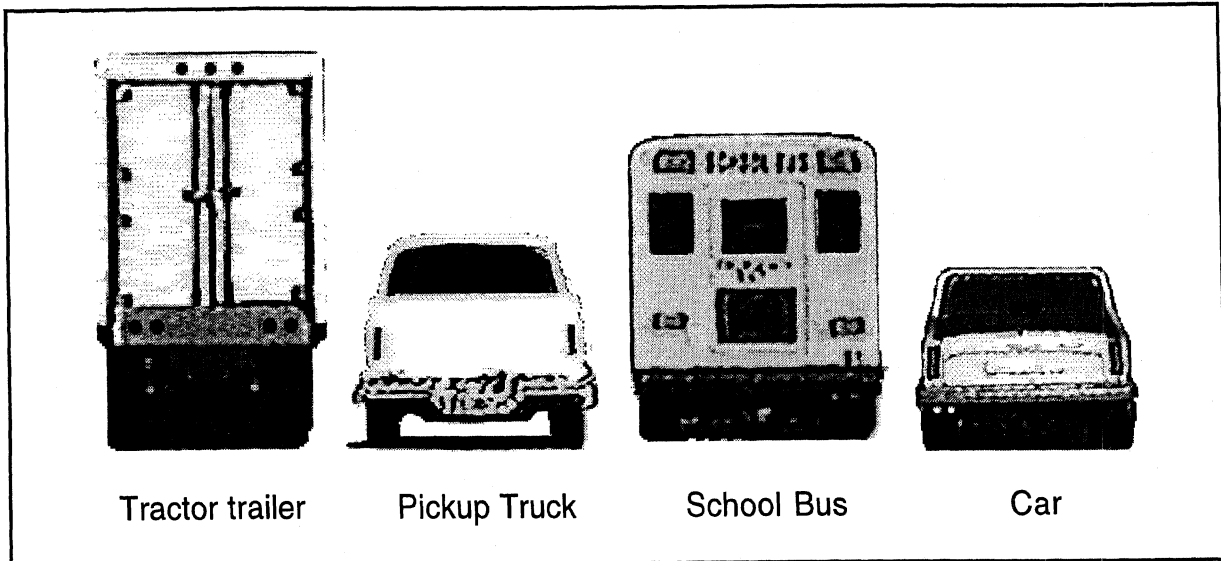
APPENDIX F - EVALUATION FORM

Subject: _____

Date: _____

Vehicle Following Study

University of Michigan Transportation Research Institute
Human Factors Division



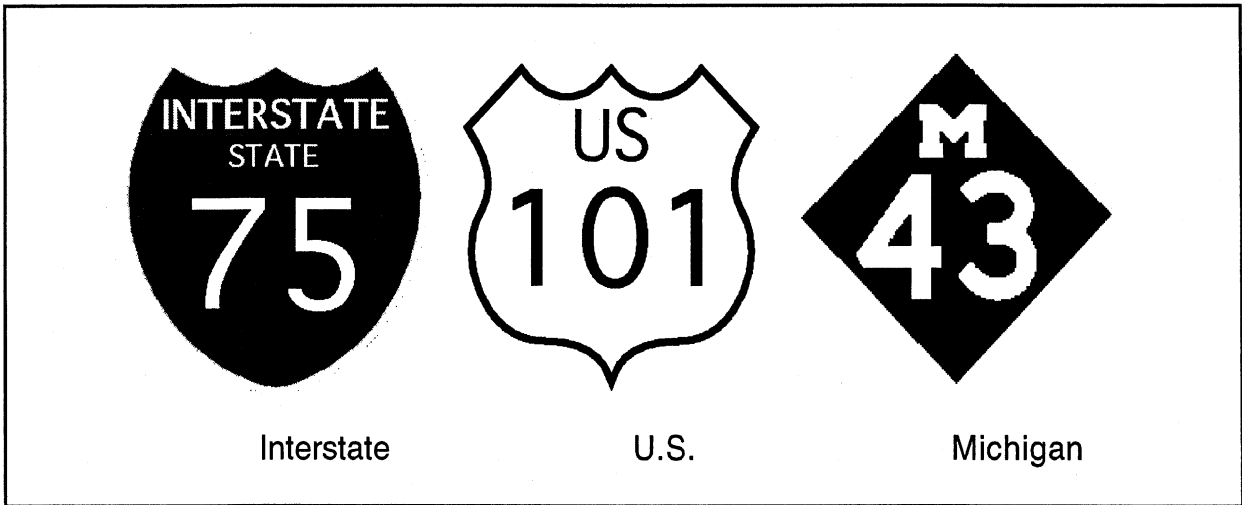
- 1) Rank the four vehicles based upon how much they blocked your vision:
(1=blocked the most ... 4=blocked the least)

Tractor trailer _____
Pickup truck _____
School bus _____
Car _____

- 2) Rank the four vehicles based upon your preferred following distance:
(1=closest ... 4=farthest)

Tractor trailer _____
Pickup truck _____
School bus _____
Car _____

- 3) What affects how closely you follow vehicles when you drive a real car?



4) Rank these signs from easiest to most difficult to recognize **while driving the simulator** (1=easiest to recognize ... 3=most difficult to recognize).

Interstate _____
U.S. _____
Michigan _____

5) What affects how easily you are able to recognize a sign?

6) Please rate the realism of UMTRI Driving Simulator:

CONTROLS

| STEERING | very artificial | | | | | | very real |
|--|--------------------|---|---|---|---|---|--------------|
| Effort required to operate the steering wheel: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Time for road scene to respond to steering wheel movement: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| ACCELERATOR | very artificial | | | | | | very real |
|---|--------------------|---|---|---|---|---|--------------|
| Effort required to operate accelerator pedal: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Time for road scene to respond to accelerator pedal movement: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| BRAKE | very artificial | | | | | | very real |
|---|--------------------|---|---|---|---|---|--------------|
| Effort required to operate the brake pedal: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Time for road scene to respond to brake pedal movement: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

GRAPHICS

| | very artificial | | | | | | very real |
|--------------------------|--------------------|---|---|---|---|---|--------------|
| Road scene appearance: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Road sign appearance: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Lead vehicle appearance: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

SOUND & VIBRATION

| | very artificial | | | | | | very real |
|---|--------------------|---|---|---|---|---|--------------|
| Sound loudness (engine and road sounds): | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Sound pitch/tone (independent of loudness, did it sound realistic?) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Vibration intensity | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Vibration frequency (independent of intensity, did it feel realistic?) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

APPENDIX G - ANOVA TABLES

Type III Sums of Squares

| Source | df | Sum of Squares | Mean Square | F-Value | P-Value |
|---------------------|-----|----------------|-------------|---------|---------|
| Sex | 1 | 91692.045 | 91692.045 | 28.421 | .0001 |
| Age | 1 | 1100196.628 | 1100196.628 | 341.017 | .0001 |
| Block | 1 | 5875.220 | 5875.220 | 1.821 | .1791 |
| Run | 1 | 11193.891 | 11193.891 | 3.470 | .0643 |
| Variance | 1 | 387.661 | 387.661 | .120 | .7293 |
| Vehicle | 3 | 35911.099 | 11970.366 | 3.710 | .0129 |
| Sex * Age | 1 | 276844.980 | 276844.980 | 85.811 | .0001 |
| Sex * Vehicle | 3 | 1721.898 | 573.966 | .178 | .9113 |
| Age * Variance | 1 | 1115.473 | 1115.473 | .346 | .5574 |
| Age * Vehicle | 3 | 4188.595 | 1396.198 | .433 | .7298 |
| Variance * Vehicle | 1 | 4717.918 | 4717.918 | 1.462 | .2283 |
| Subject (Sex, Age) | 12 | 1631805.962 | 135983.830 | 42.150 | .0001 |
| Sex * Age * Vehicle | 3 | 5340.669 | 1780.223 | .552 | .6477 |
| Residual | 159 | 512969.997 | 3226.226 | | |

Dependent: Headway(mean)

Type III Sums of Squares

| Source | df | Sum of Squares | Mean Square | F-Value | P-Value |
|---------------------|-----|----------------|-------------|---------|---------|
| Sex | 1 | 10330.803 | 10330.803 | 24.981 | .0001 |
| Age | 1 | 2261.000 | 2261.000 | 5.467 | .0206 |
| Block | 1 | 65.901 | 65.901 | .159 | .6903 |
| Run | 1 | 3.469 | 3.469 | .008 | .9271 |
| Variance | 1 | 175.024 | 175.024 | .423 | .5163 |
| Vehicle | 3 | 1862.425 | 620.808 | 1.501 | .2164 |
| Sex * Age | 1 | 2524.986 | 2524.986 | 6.106 | .0145 |
| Sex * Vehicle | 3 | 7087.722 | 2362.574 | 5.713 | .0010 |
| Age * Variance | 1 | 28.976 | 28.976 | .070 | .7916 |
| Age * Vehicle | 3 | 650.034 | 216.678 | .524 | .6664 |
| Variance * Vehicle | 1 | 60.296 | 60.296 | .146 | .7031 |
| Subject (Sex, Age) | 12 | 93867.855 | 7822.321 | 18.915 | .0001 |
| Sex * Age * Vehicle | 3 | 560.707 | 186.902 | .452 | .7163 |
| Residual | 159 | 65753.522 | 413.544 | | |

Dependent: Headway(SD)

Type III Sums of Squares

| Source | df | Sum of Squares | Mean Square | F-Value | P-Value |
|---------------------|-----|----------------|-------------|---------|---------|
| Sex | 1 | .255 | .255 | 3.070 | .0817 |
| Age | 1 | 3.887 | 3.887 | 46.748 | .0001 |
| Block | 1 | .026 | .026 | .311 | .5779 |
| Run | 1 | .145 | .145 | 1.740 | .1891 |
| Variance | 1 | .038 | .038 | .455 | .5009 |
| Vehicle | 3 | .105 | .035 | .420 | .7392 |
| Sex * Age | 1 | 6.365 | 6.365 | 76.561 | .0001 |
| Sex * Vehicle | 3 | .242 | .081 | .971 | .4079 |
| Age * Variance | 1 | .019 | .019 | .232 | .6310 |
| Age * Vehicle | 3 | .104 | .035 | .418 | .7402 |
| Variance * Vehicle | 1 | .025 | .025 | .305 | .5813 |
| Subject (Sex, Age) | 12 | 27.930 | 2.327 | 27.994 | .0001 |
| Sex * Age * Vehicle | 3 | .449 | .150 | 1.799 | .1495 |
| Residual | 159 | 13.219 | .083 | | |

Dependent: YPos(mean)

Type III Sums of Squares

| Source | df | Sum of Squares | Mean Square | F-Value | P-Value |
|---------------------|-----|----------------|-------------|---------|---------|
| Sex | 1 | .543 | .543 | 15.598 | .0001 |
| Age | 1 | .024 | .024 | .680 | .4107 |
| Block | 1 | .003 | .003 | .092 | .7617 |
| Run | 1 | .017 | .017 | .476 | .4912 |
| Variance | 1 | .029 | .029 | .829 | .3639 |
| Vehicle | 3 | .016 | .005 | .155 | .9264 |
| Sex * Age | 1 | 1.987 | 1.987 | 57.065 | .0001 |
| Sex * Vehicle | 3 | .022 | .007 | .214 | .8865 |
| Age * Variance | 1 | .015 | .015 | .444 | .5063 |
| Age * Vehicle | 3 | .014 | .005 | .133 | .9405 |
| Variance * Vehicle | 1 | .057 | .057 | 1.628 | .2039 |
| Subject (Sex, Age) | 12 | 3.440 | .287 | 8.235 | .0001 |
| Sex * Age * Vehicle | 3 | .048 | .016 | .460 | .7103 |
| Residual | 159 | 5.535 | .035 | | |

Dependent: YPos(SD)