Technical Report

Field Measurement of Naturalistic Backing Behavior

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16. Abstract

A series of observations and measurements were made as 21 subjects drove their own vehicles in an assortment of naturalistic backing tasks. The tasks were performed on public roads in real world driving conditions. As the subjects performed the eight tasks, the following data were collected: glance direction, hand position, car speed, and distance to object in back of the vehicle. The results provide a set of normative data usable by automotive system designers for the design of backing warning systems, or other products or environments related to backing. The results were divided into glance direction, backing speed, and time-to-collision. Glance. directions were found to vary greatly between tasks, and were distributed widely around the vehicle. Elderly drivers demonstrated a preference for using their mirrors and looked over their shoulder less then the young subjects. Except for the extended backing maneuvers, backing speeds averaged around 3 mph. The maximum backing speed for the young drivers was faster than the elderly and males backed faster than females. Time-to collision values were approximately the same for males and females as well as young and old. Time-to-collision tended to remain relatively constant as the vehicle backed toward on object. The minimum times-to-collision exceeded 1.0 s, and usually exceeded 2.0 s.

17. Key Words

ITS, crash avoidance warnings, backing

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1.0 BACKGROUND

In order to design an in-vehicle backup warning system, it is essential to understand the behavior of drivers while backing. This includes information about the sequence of events, glance direction, backing velocity, age, task and individual differences. This information is critical in determining the alarm modality, timing, location and adaptability that is required to implement a backup warning system.

The present study the first in a sequence of experiments that will define the appropriate human factors requirements for in-vehicle back-up warning user Iinterfaces It addressed various key gaps in existing knowledge that were identified in the development of preliminary recommendations in the Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices report. Very little empirical information exists on the nature, sequence, and timing of behaviors that occur under various vehicle backing scenarios. Information about driver behavior will be critical for addressing such issues as the location of warnings, the modality and nature of warnings, the timing of warnings, the parameters that define a hazardous situation, and the need for individually adaptive interfaces for user control. This experiment measured a range of driver behavior variables as drivers made backing maneuvers in their own vehicles under a range of naturalistic backing scenarios. The findings provide a descriptive database that will be useful for those concerned with backing maneuvers in general, and will contribute to the development of driver warnings in particular.

2.0 OVERVIEW OF DESIGN/PROCEDURE

This experiment was designed to collect data in a natural setting. Participants used their own vehicles, which included cars, minivans, and utility vehicles, and drove on public roads. The ability to record drivers in the normal operation of their own vehicles allowed measurement of “normal,” ecologically valid performance, such as typical velocities, distances, and mirror use. An unfamiliar vehicle might have altered this behavior, and would also have limited the findings to a specific vehicle make and model, which might be atypical.

An experimenter directed drivers through a course that included a wide range of backing maneuvers. A data collection system was temporarily installed in the participant’s vehicle to record measures of driver behavior and vehicle control. The instrumentation suite included video and digital data collection based on a variety of vehicle and external sensor measures. A cover story was used that described the study as an evaluation of vehicle measurement equipment. This slight deception was necessary to reduce participant reactance to being observed when backing. Participants were thoroughly debriefed upon completion of the drive.

The several backing scenarios included in the course covered a range of typical situations related to parallel parking, parking in lots, and backing in driveways or roadways. The variables measured included brake and accelerator use, gear changes, direction and duration of looks, vehicle speed, distance from objects, time-to-collision, and the sequence and timing of driver actions.

3.0 PARTICIPANTS

Twenty four drivers participated in the study, and useable data was obtained from 21 participants. Licensed drivers from the local area and seniors citizens groups were recruited through telephone calls. Participants were informed that the research was NHTSA-sponsored, that instrumentation would be attached to their vehicles, and that they would be required to perform a variety of driving maneuvers with an experimenter in their vehicle. A variety of vehicle types were used in the study and included cars (n=17), utility vehicles (n=3), and minivans (n= 1). The age group and gender distribution is presented in Table 3-l. Figure 3-l is a histogram showing the distribution of participant ages. During recruitment, the caller described the backing maneuvers that would be required. Only those persons who felt comfortable performing these maneuvers were invited to participate. This screening ensured that during the study, participants did not perform maneuvers that they routinely avoided. However, not having recently executed a particular backing maneuver (e.g., backing out of a curved driveway) did not constitute grounds for exclusion.

Table 3-l. Distribution of Age and Gender

		Age	
		Young	Old
		20-31 mean=22.5	67-81 mean=73
Gender	Male	7	4
	Female	5	5

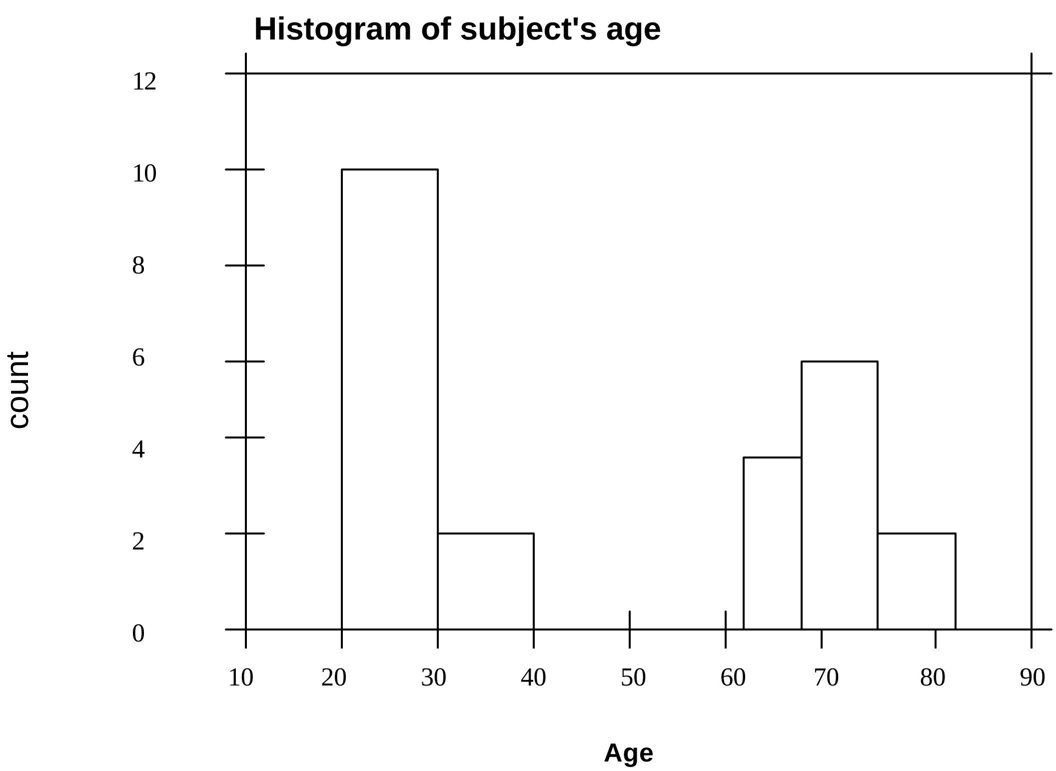

Figure 3-1. Histogram of age

4.0 APPARATUS

The apparatus for this experiment allowed collection of both video and digital data from the vehicle and driver. All data collection equipment was controlled from a single PC located in the back seat of the vehicle with the experimenter (see Figure 4-l). The PC used a custom application written in Microsoft VisualBASIC to control the entire suite of equipment for data collection, reduction, and post processing procedures. The following description outlines the full suite of equipment:

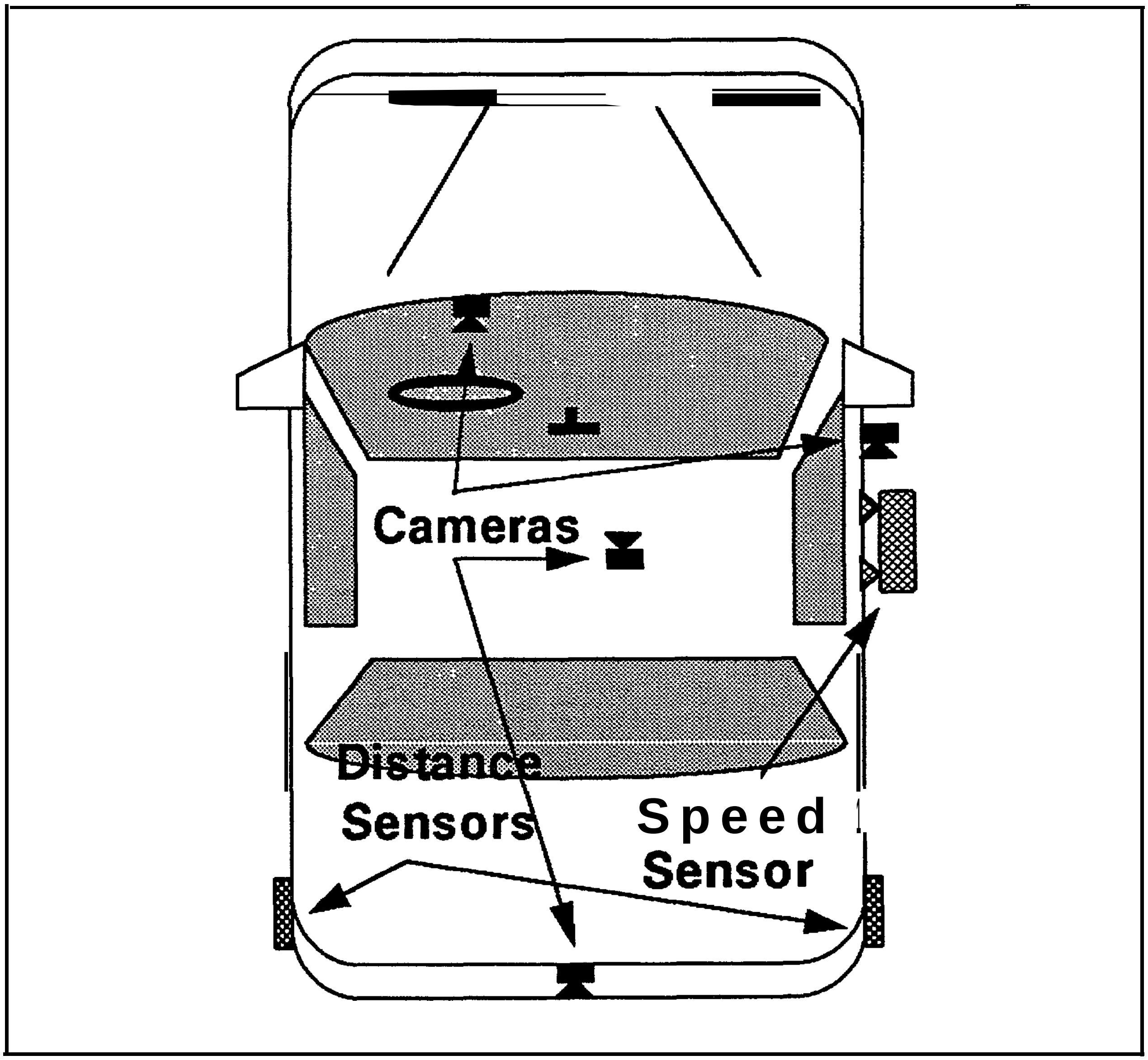

Figure 4-l. Data collection hardware configuration

- Miniature Camera Systems - These cameras were mounted to the vehicle in order to get a picture of driver glance behaviors (i.e., direction and duration). Four ProVideo model CVC-300 cameras were used. Figure 4-l depicts the locations of the cameras. These locations included two mounted inside the passenger compartment; one on the dash to capture most driver glances including mirror use and head turns, and one on the rear deck pointed to capture gear shift use, some forward looking references, and additional detail for defining glance parameters. Two outboard locations were also used; one on the rear end of the vehicle pointed backward and one mounted near the passenger side mirror pointed backward along the edge of the vehicle. Infrared illumination made capture of video data possible in poor ambient illumination conditions, though all trials were performed during the daytime.

- **Optical Speed Detector** - This component, a DATRON model DLS2, allowed accurate detection and computer input of speed data to be collected by the computer. This speed data was used to derive velocity and acceleration information for data analysis purposes. This device was typically mounted on the passenger side of the vehicle, taking care to minimally obstruct the driver's view through side view mirrors or direct looks toward the rear of the vehicle. Output from the device was in speed (i.e., no direction indication) so this information had to be coded during the data reduction process.

- **Distance Measurement Instruments** - Two SonaSwitch model 1750 ultrasonic sensors were used to collect information about the distance to an object for the conditions in which backing to an object or parking in close proximity to other objects or vehicles was involved. These instruments used ultrasonic technology to provide accurate measurement of the distance up to about 30 feet from the detector to the object in real-time for collection on the computer.

- **Personal Computer** - An IBM ThinkPad model 360CSE computer was used as the data collection and reduction platform. It housed boards to control the data acquisition processor and speed detector as well as controlling the recording parameters of the VCR.

- **Computer-Controlled VCR** - A computer controlled VCR (Sony model CVD 1000) collected video data from all four cameras after combination within the quad splitter. Time code was applied to the videotape to allow a frame accurate indication of events that occurred during the experiment. This time code provided the time base for all data collection and reduction activities.

- **Quad Splitter** - This component allowed up to four video sources to be combined on a single VCR image.

- **Data Acquisition System** - This component, an IOtech model Daqbook 100, allowed digital and analog data to be collected form a variety of sources during the drive. These sources included the speed sensor, distance measurement device, and accelerator, shifter, and brake use indicators. Data was collected at 3OHz to match the video frame rate and associated time code accuracy provided by the computer-controlled VCR.

- **Power Supply** - Because some of the equipment required 120 VAC power, an inverter and separate backup battery was required. Power was supplied by the subject's vehicle to the extent possible from cigarette lighter connection. The 250 watt power inverter supplied ample power to the operate the computer, VCR, quad splitter, and video monitor. All other components were operated directly from 12VDC power. The backup battery was used to ensure constant current levels during situations when vehicle power was insufficient. This occasionally occurred when air conditioners or other vehicle accessories were initially activated during the drive.

- **Pressure sonsors** - Force sensing resistors (FSR) were located on the brake, shifter, and accelerator and held in place by elastic straps. They provided analog (convertible to digital) output related to the pressure applied to them. Essentially, the resistance in these devices drops in relation to the amount of pressure applied to their surface.

- **Video Monitor** - A small (2.9" diagonal) video monitor (Citizen model M329 MKII) provided a constant view of all four cameras to the experimenter and provided feedback during preliminary aiming for each session.

5.0 EXPERIMENTAL DESIGN

5.1 Independent Variables

This experiment considered three factors as independent variables: age, gender, and backing scenario. The age and gender distribution of the subjects can be found in Table 3-l. A representative sample of backing scenarios that drivers encounter on a routine basis was chosen. While not exhaustive, these situations provided a broad set of situations with varying perceptual and control activity demands upon the driver. Six general backing scenarios were included in the study. Two of these were repeated under two somewhat different settings, so that a total of eight backing sites were included in the experiment. The six backing scenarios were as follows:

- Extended curved backing to a stop point (2)
- Parallel parking against a curb with vehicles fore and aft (2)
- Packing out of a perpendicular slot in a parking lot
- Backing out of an angle slot in a parking lot
- Backing into a wall
- Backing into a perpendicular parking slot

All sites were located in and around Silver Spring, Maryland. These sites were as follows:

Site 1: Angled parking condition - This site was located inside a parking garage. Participants were instructed to pull into a particular slot between two adjacent vehicles and then back out. Specifically, there were angled parking slots along both sides of a one-way traffic lane. The lane was about 20' wide with the parking slots measuring 7' wide and 16' deep. Traffic was not heavy in this location, bu' there were several instances when traffic interrupted a participant's backing from a slot.

Site 2: Parallel parking condition - This site was located on Spring Street, a median divided, two-way street with curb-side metered parking. The particular location of each session varied with availability of suitable spots. Either a northbound or a southbound direction was chosen depending on availability. The traffic in this area was relatively light, although occasionally other traffic would interfere with participant attempts to parallel park. Roadway width was 24' from curb to curb, allowing other vehicles to pass, even during early phases of the parallel parking maneuver in which vehicles were fully in the travel lane of the street. only spots that included vehicles fore and aft were selected. Participants were instructed to pull past the slot and perform a parallel parking maneuver. Parking meter spacing provided ample room for even the largest of vehicles and the relative location of the **fore and aft** vehicles provided more room in some cases. Generally, available space was fairly **consistent with parking meter spacing** at about 22'.

Site 3: Extended curved backing condition - This site was located on a parkway. This **location was a** small **parking area with an extended left curving drive provided as an exit.**

Participants were asked to pull through to the end of the exit and then back along the curved drive to the parking area. Several feet of unused buffer zone were afforded on either end of the drive to ensure safety. In a small number of cases, a vehicle was parked along the edge of the drive, making backing somewhat more difficult but this was typically near the end of the backing sequence rather than in the middle of the maneuver. For this site, as with the other curved backing maneuver site, a single marking stripe was placed on the roadway at either end of the segment. For this site, these markings were separated by about 140' and the lane width was approximately 16'. This stripe was not conspicuous or distracting to the participants, but provided a consistent cue to the staff during data reduction. As the participants drove into the curved sites, the experimenter ensured that they pulled past the second stripe and that they backed past the first stripe during their backing maneuver. These two events were designated as the beginning and end of a given participant's maneuver at these sites. These were the only sites in which this marking method was used. No curbs were present along this section.

Site 4: Wall condition - This site was comprised of a ten foot high wall within an apartment complex parking lot, to which participants were instructed to back. There were no parking stop blocks in front of the wall, so drivers were able to pull as close to the wall as they wished. Participants were instructed to pull into the parking lot, to position themselves in order to back up to the wall, and to disregard the parking stripes. This maneuver was performed in various locations along this wall to allow sufficient width between adjacent vehicles for comfortable backing. The parking slot dimensions were about 19' deep and 9' wide with a wide aisle for approaching the slots.

Site 5: Perpendicular parking condition (back out) - This site was located in a public parking lot. Participants were instructed to simply pull into and back out of a spot that had other vehicles on both sides as well as vehicles behind in order to provide a typical parking maneuver in a crowded lot. Passing traffic was minimal. The dimensions of these parking slots were about 14' deep by 7' wide with a 24' two-way aisle separating the slots from similar opposing slots.

Site 6: Perpendicular parking condition (back in) - This site was located in a library parking lot. In this case, participants were asked to back into a parking slot that had vehicles on both sides and a concrete curb to the rear. The dimensions of these parking slots were about 16' deep by 8' wide with a 25' two-way aisle separating the slots from similar opposing slots. Typically, this curb was not detected by the ultrasonic distance sensors. In several cases, participants had to be warned that they were close to other vehicles. Interfering traffic was minimal.

Site 7: Parallel parking condition - This site was located on a two-way undivided street with parallel spaces on either side. The street is approximately 44' from curb to curb with 22' spacing between parking meters. Traffic was somewhat lighter in this condition than in the Site 2 parallel parking condition. Instructions and distance measuring potential were similar to that available at Site 2.

Site 8: Extended curved backing condition - This site was located on a dead end section of roadway off of a minor road. Typically, no traffic was present in this location. The drive curved left slightly near the entrance from the intersecting side street. The road was slightly uphill for the backing maneuver. Participants were instructed to drive to the end of the dead end and then back out to the street. There were residences on either side of the street with no curbs, but several mailboxes next to the street. On one side of the street, one lawn had railroad ties as a border about 1' into the lawn. Specifically, the drive measured just over 200' and was approximately 12' wide over most of its length. In some cases, delivery or visiting vehicles were parked on the driver's side of the drive, but normally provided adequate width to pass by these other vehicles.

5.2 Dependent Measures

Dependent behavioral and vehicle-based measures are outlined in Table 5-l.

Table 5-l. Behavioral and Vehicle-based Dependent Measures

Type of Measure	
Behavioral	**Vehicle-based**
Glance direction*	**Distance to object**
Glance duration*	Time-to-collision
Brake use+	Speed/Acceleration
Accelerator use+	
Gear selector use*	

*** this measure was manually reduced from video data and linked to the automated database files for each participant**

† this data was collected but deemed too unreliable to be useful

6.0 PROCEDURE

6.1 Informed Consent and Instructions to Participants

Initially, the experimenter greeted the participant and asked him or her to read and sign the informed consent form. The experimenter then read a set of instructions (see Appendix A) outlining the requirements of the participant for participation in the experiment. Participants in this experiment were asked to drive their own vehicles through a variety of situations while data was collected. A cover story was used to minimize driver reactance to the instrumentation and experimenter during the drive. Participants were told that instrumentation for measuring vehicle performance parameters was being evaluated. Therefore, aspects of driver performance were not an explicit dependent measure and their individual performance was not at the heart of the study.

6.2 Instrument Installation and Calibration

The data collection instrumentation was installed in each participant's vehicle before the experimental trial began. This installation involved loading the bulk of the electronics (i.e., VCR, quad splitter, DdqBood inverter, and battery) into the trunk of the vehicle and then routing and attaching cables and sensors to various points on the interior and exterior of the vehicle to capture the measures of interest. The four miniature CCTV cameras were mounted as shown in Figure 4-l to capture driver glance direction, gear shift use, hand position, an exterior forward view, directly behind the vehicle exterior, and along the passenger side exterior. These views were then combined using a quad splitter and recorded by the VCR located in the trunk. All cameras were attached with suction cup mounts with the exception of the cockpit/forward view camera. This camera was typically strapped to the passenger seat near the head rest. This camera also collected audio. The ultrasonic distance sensors were attached with suction cups to the rear comers of the vehicle about two feet above the ground. The optical speed sensor was also attached with suction cups and was located on the passenger door. Brake, gas and shift sensors employing force-sensing resistor (FSR) technology were held in place with rubber straps fashioned from bicycle inner tubes. This attachment means was effective in terms of securement reliability, but the inherent pressure imparted to the sensors from this mounting means masked some of the valid actuations to the point that much of the data from these devices unusable.

Once the instrumentation was installed, calibration was performed on the ultrasonic and FSR sensors using a special program within the data collection software (see Figure 6-l). Calibration of the ultrasonic distance sensors essentially placed the 0" point of the sensor at the edge of the back bumper, thus converting all measurements to analogous distance to the rear of the vehicle. FSR calibrations involved determining the threshold level of the sensor for use in creating an ON/OFF indication for each participant touch. This calibration was set by simply touching the control lightly and setting the threshold to the maximum value possible without getting too many false alarms and without having to push too hard on the sensor to trigger an actuation. This was, however, a fairly subjective process, and in'many cases, caused non-optimal threshold selection problems to go undetected. Future implementations of this technology will seek to avoid this shortcoming.

Participant and vehicle demographics were also entered at this time in the data collection software (see Figure 6-2). Participant age, number, gender, and name were entered as well as vehicle make, model, year, brake and transmission type. This information was saved with the calibration parameters in an ASCII file separate from the time-based data.

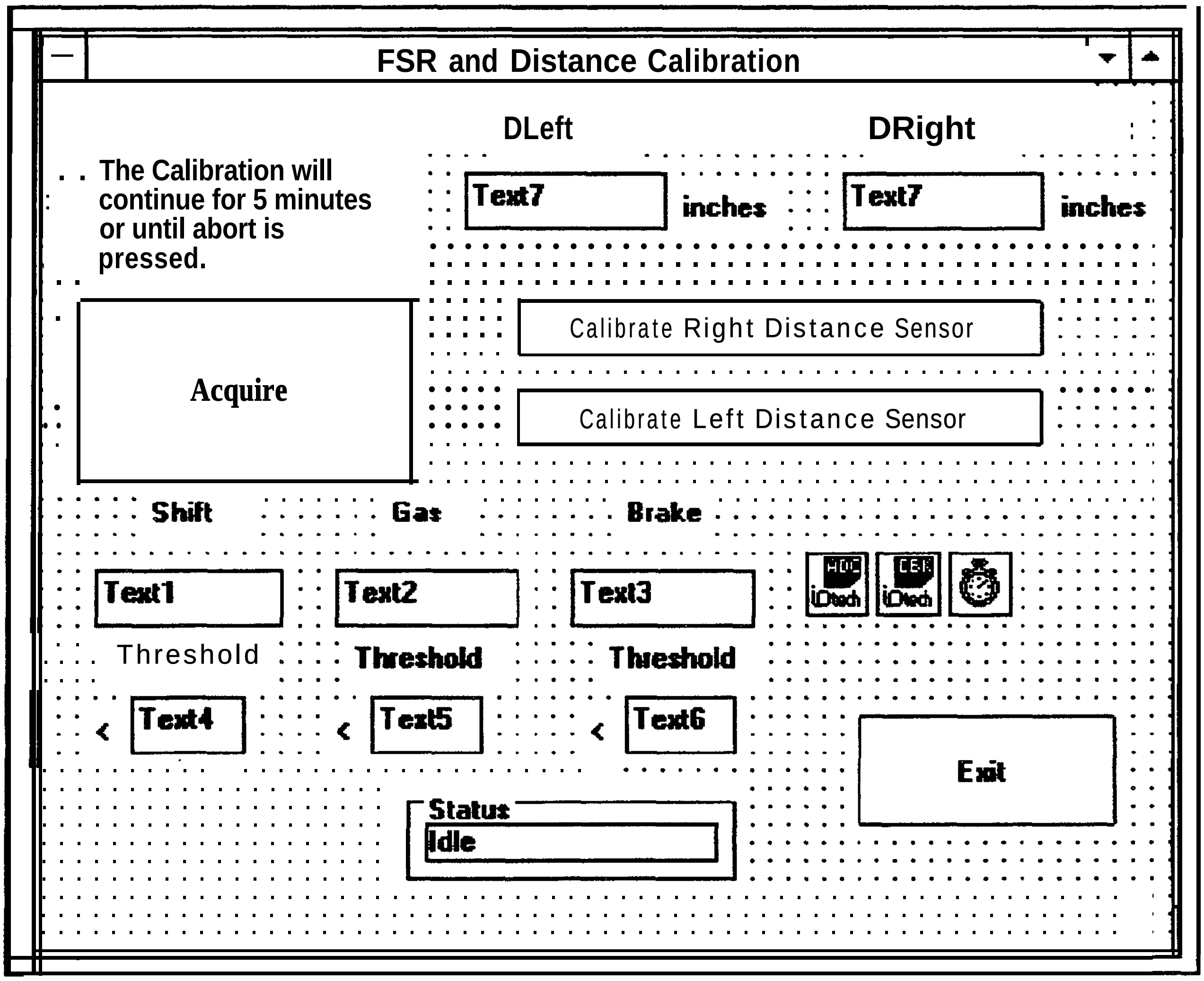

Figure 6-l. Interface used for FSR and distance sensor calibration.

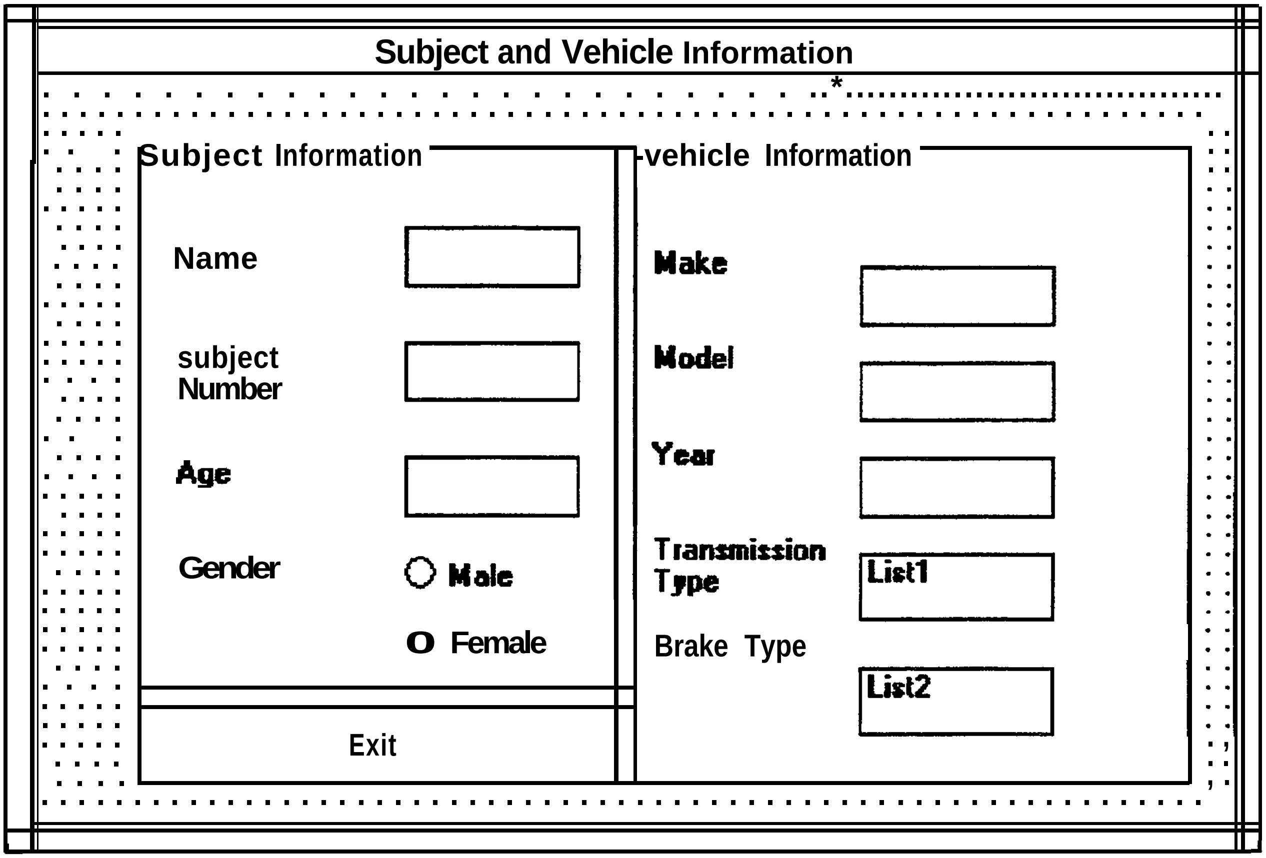

Figure 6-2. Interface used for participant and vehicle demographics entry.

6.3 Experimental Trial

The experimenter rode with each participant and provided directions to each backing site as well as telling the participant where and how to perform each desired task (if there were specific, non-intuitive guidelines for completion). Participants were instructed to drive as they normally would drive. They drove along a route within the Silver Spring, MD area while an experimenter rode in the back seat, directly behind the driver. If necessary, the experimenter ducked down in the back seat during backing exercises (i.e., to avoid obstructing the participant's view). Whenever necessary, the experimenter provided verbal guidance to help the participant maneuver the vehicle. To the extent possible, the location and stimulus for each participant remained the same for purposes of experimental control. However, for some parking lot situations, different slots had to be used for each iteration based on availability.

For each site, the participant was asked to enter the parking spot in the manner specified by the experimental design at a speed comfortable for them. In every case, participants were instructed to park (or back-up) in their normal fashion to enter (or exit) the parking spot.

They were also instructed to go as fast or as slow as they felt comfortable driving to accomplish the tasks The site presentation order was varied between participants to control for order effects.

During each backing trial, digital and video data was collected from within the instrumented vehicle. Data outlined in the Independent Measures section (5.1) of this document was collected and time coded. Figure 6-3 shows the interface used by the experimenter to control the data collection system. Collecting data involved guiding participants to a predefined location and then covertly collecting key measures for a period of time surrounding a particular backing maneuver. By selecting the appropriate option button corresponding to the site being navigated and pressing the "Begin Collecting Data" button, data was collected and then saved to an ASCII file identified by the participant number. Pressing the same button again stopped the data collection. A record was written each 30th of a second and included site and participant identification, analog data values and the time code associated with that point on the video tape. Participants progressed through each of the backing exercises until all had been completed. Then, the participant returned to the staging area, where the technician removed the instrumentation from the vehicle. Participants were then paid for their time and dismissed. The entire study took about two and a half hours including installation and calibration.

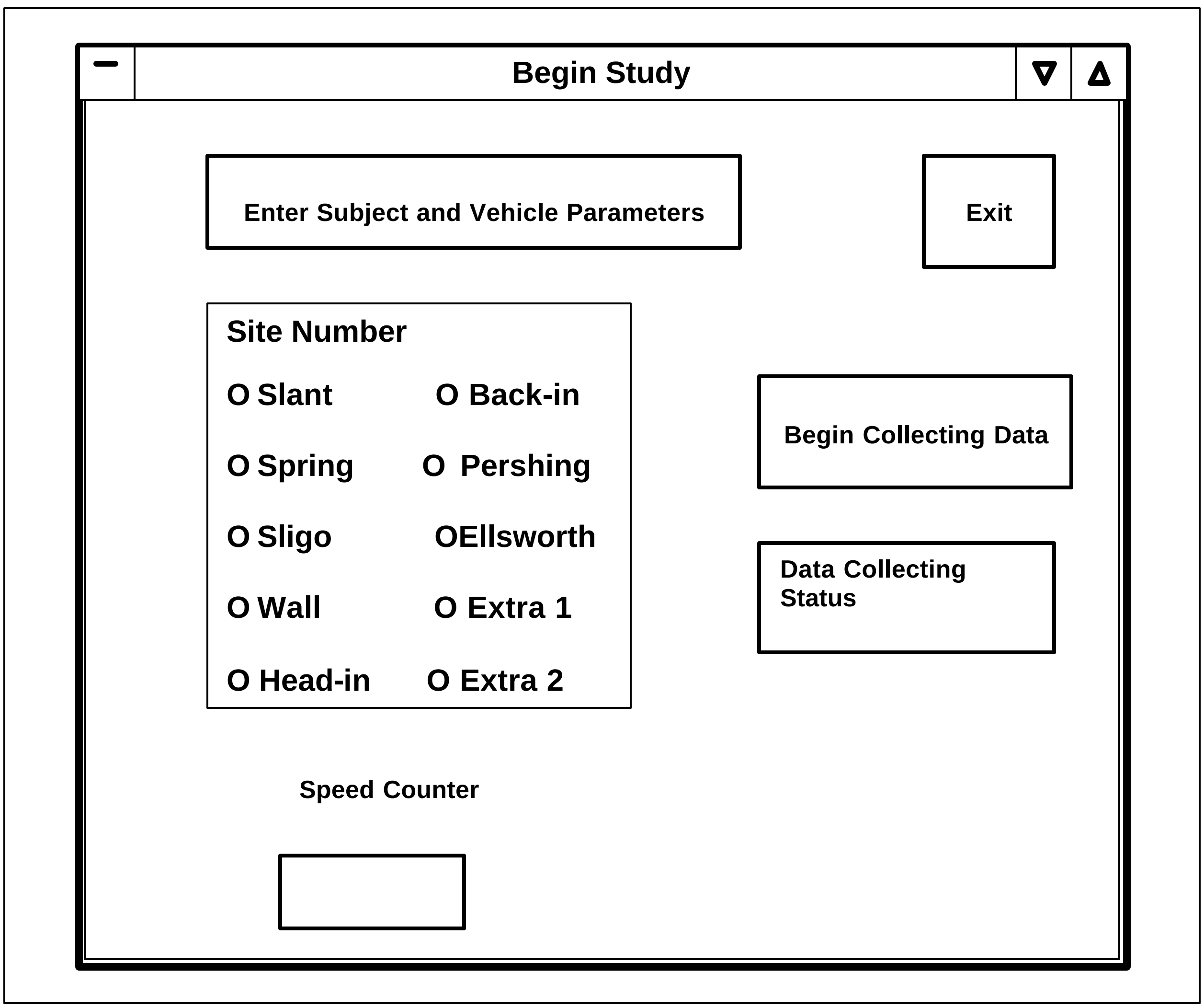

Figure 6-3. Interface used by the experimenter to control data collection system.

6.4 Data Reduction

At the end of the data collection process two distinct products were evident; a videotape of the entire session, and a data file representing the analog and digital sensor measurements for the various maneuvers performed by the participant. The primary purpose of the data reduction procedure was to integrate the products into an "enriched" data file that could be analyzed using conventional statistical analyses. In the preprocessing phase of reduction, each raw participant file was read into a Visual BASIC array to speed reduction process search performance.

The reduction process was a crucial step in which the data from different participant files were standardized by establishing trial start and end points for each site and enhanced with indications of driver hand position, glance direction, and direction of vehicle motion. A custom user interface allowed complete control of the VCR from the data reduction computer as well as providing means to search for key points in the digital and video records (see Figure 6-4). To begin the process, a participant's data file was loaded and one of the sites was selected from a list. The software then found the first record for that trial and moved the videotape to the corresponding position. The trial starting point for most sites was 3 seconds prior to the beginning of the first stop and the end point was 3 seconds after the end of the last stop. This logic provided a consistent window for all participant data as well as some footage before and after the actual backing maneuver. For some sites visual markers were used, instead, to establish these points. After establishing these boundaries for a given trial, participant behavioral actions were indicated by manual input from data reduction technicians. This manual process was typically performed by making three passes through each trial, indicating a different variable on each pass. First, whenever there was a change in the direction of motion (the sensor only provides absolute values of speed, not velocity), it was manually indicated and recorded using the relevant option buttons in the upper right corner of the reduction software display. Next, the glance direction was recorded. There were ten (10) possible position variants for the glance direction. Every time there was a change in direction, it was recorded by clicking the appropriate option button in the glance direction area of the display. Lastly, for hand position, every time there was a change it was recorded by clicking one of the seven option buttons related to it. To enter a change in any of the above mentioned variables, the video first had to be paused to ensure proper entry of the information. This process was repeated for all eight sites.

Once all the sites for a participant file were reduced, a post-processing algorithm was used to fill in the blanks between manual reduction indications and generate separate ASCII files with specific data analysis characteristics. The four files are listed below according to their individual file extensions:

- **ACC** - Provides a set of smoothed acceleration and velocity readings.
- **TTC** - Provides velocity and time to collision calculation for sites in which backing to a detectable object occurred.
- **DEB** - Provides the most comprehensive data set including all sites with human and

vehicle performance indications and unsmoothed velocity data
- .EVE - Provides an event-based data file with one record for each change in a human (glance or hand position) or vehicle (starts and stops) performance factor

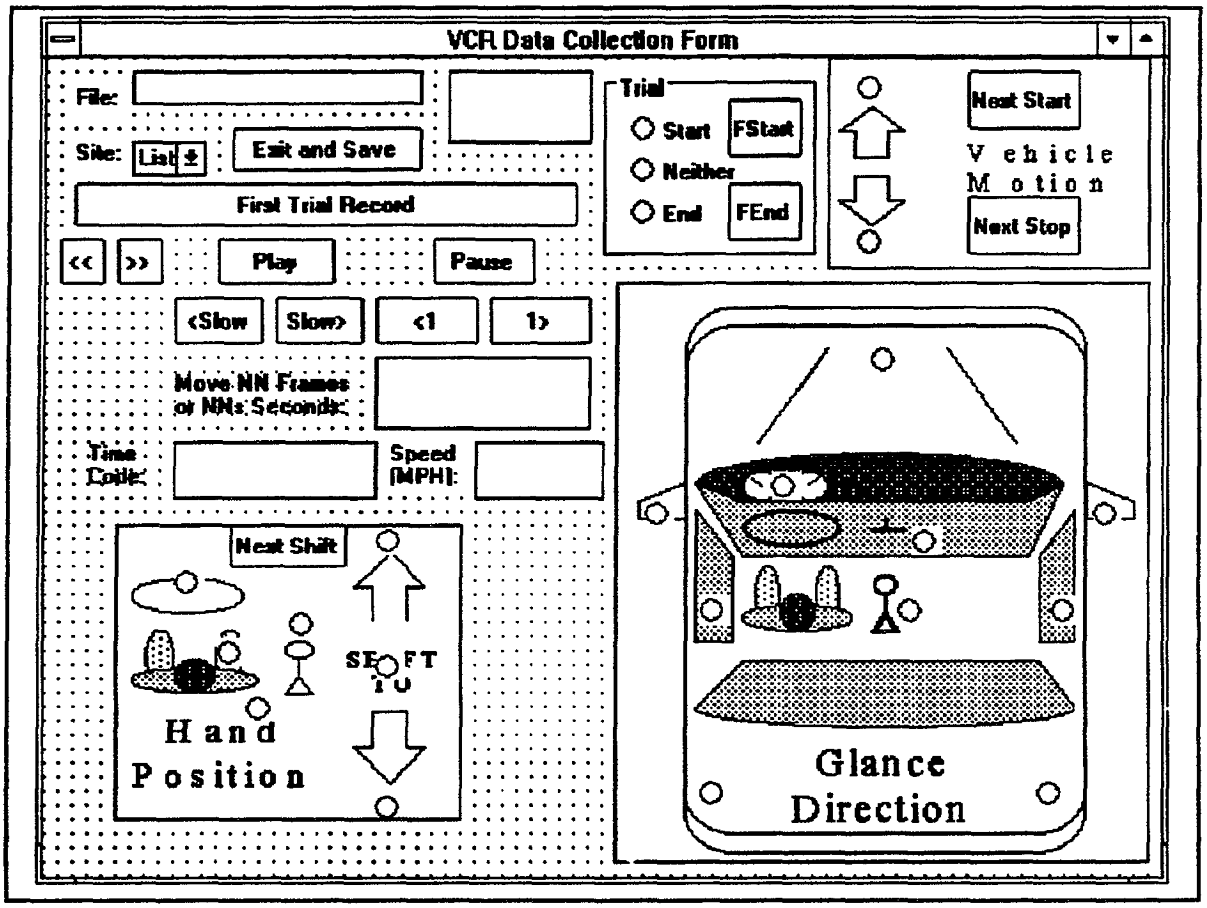

Figure 6-4. Interface used for reduction of video data.

7.0 RESULTS

The major research questions addressed by this experiment include the following categories of behavioral measures that were derived from the direct measures outlined in the experimental design:

- **Looking behaviors** - One of the objectives of this research was to evaluate the plausibility of various locations for a visible warning device display. Failure to use a location that is reliably scanned by the majority of drivers during backing would adversely affect warning effectiveness.

- **Individual differences** - Drivers may exhibit quite different behaviors in terms of frequency and magnitude of looking, control activations, or speed and distance preferences. These differences may point to a need for individualized (adjustable or adaptive) settings on the sensors or output devices for backing aids or warning user interfaces. Our analysis considered these differences and identified those that appear to be significant in designing the necessary flexibility into device designs.

- **Discrimination of "errors"** - A critical product of this research effort will be the development of an "envelope" of normal backing. In other words, we must define what normal backing looks like in order to define what constitutes abnormal (or backing indicative of an imminent crash) backing. This analysis included a characterization of typical backing behavior in terms of backing speeds and acceleration rates, acceptable proximity distance and time associated with various components of the backing scenarios.

Eight tasks were performed by each participant as described in Section 5.0. The names for the tasks are abbreviated in the following tables. The abbreviations are as follows:

Abbreviated name	Full name
1. Back Angle	Backing out of an angled slot
2. Parallel	Parallel parking
3. Extended curve	Extended curved backing
4. Back wall	Backingtoawall
5. Back out perp	Back out of a perpendicular parking slot
6. Back in perp	Backing into a perpendicular parking slot
7. Parallel	Parallel parking
8. Extended curve	Extended curved backing

The results are broken down into the following categories:

1. **Glance direction**
   - **- across all participants and tasks**
   - **- by participant and task**

- by task
- by age
- by age and task
- by gender
- by gender and task
- when starting to backup
- one second into backup sequence

2. Maximum backing speed
   - by participant and task
   - by task
   - by age and task
   - by gender and task
   - sample of velocity profile for a task
3. Minimum time-to-collision (TIC)
   - by participant and task
   - by task
   - by age and task
   - by gender and task
   - sample of typical TTC graphs
4. Time versus distance for each task

7.1 Glance Direction

Glance direction was determined by manually examining the video recorded during each of the backing tasks. Of particular interest was the glance direction during the backing phase of each task. Special purpose displays were developed to display the glance direction data. These displays consisted of a schematic of a vehicle with nine boxes spaced around the vehicle. Each box contains the percentage of the time the participant was looking in that direction while the vehicle was moving in reverse. Additionally, on the lower left hand side of the figure a table lists the total backing time for that task.

7.1.1 Glance Direction Across All Participants and Tasks

The percentage of glances in each direction across all participants and tasks was computed. This information is shown in Table 7-l. These means show that a driver's glance direction varies greatly from direction to direction. Figure 7-l shows the mean percent glance duration for all subjects for each task using the special purpose display mentioned above.

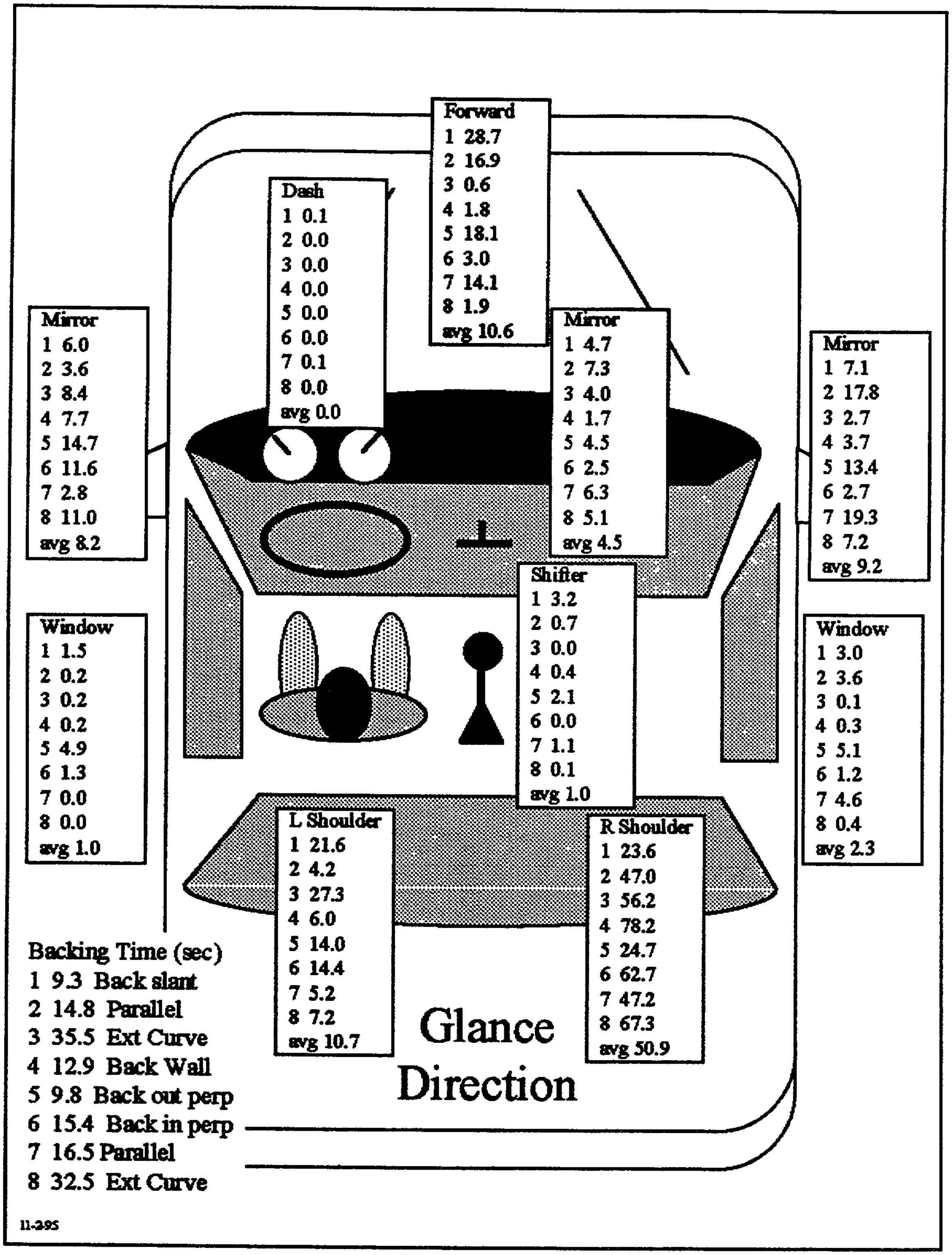

Figure 7.1 Average percent glance duration for all subjects while moving backward sorted by task.

Table 7- 1. Average glance direction across all tasks for all participants.

Glance Direction	Percent glance direction across all tasks and all participants
Forward	10.6%
Dash	0.0%
Driver's mirror	8.2%
Rear mirror	4.5%
Right mirror	9.2%
Right window	2.3%
Left window	1.0%
Shifter	1.0%
Left shoulder	10.7%
Right shoulder	50.9%

7.1.2 Glance Direction by Participant and Task

The figures for each participant are shown in Appendix B. These figures show the percentage of the time the drivers looked in each direction while moving in reverse. These data reveal large individual differences within and between tasks. When examining within participant differences it is useful to note that tasks 2 and 7 are both parallel parking and tasks 3 and 8 are both extended curved backing. For comparison purposes the glance data from 3 participants was broken down for glance during reverse, glance while stopped, and glance while moving forward. These data are also shown in Appendix B.

7.1.3 Glance Direction by Task

Appendix B contains a more detailed table for each task and the breakdown of glance across all participants. The table below shows the mean glance duration for each direction across all tasks while moving in reverse. As can be seen in Table 7-2, there are great differences from task to task. For example, Task 1 (backing out of a angled slot) drivers looked forward 28.7% of the time while moving in reverse. For task 3 (extended curved backing) participants only looked forward 0.6% of the time.

Table 7-2. Percent glance direction across all participants.

Glance Direction	Task 1	Task2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8
Forward	28.7%	16.5%	0.6%	1.8%	18.1%	3.0%	14.1%	1.8%
Dash	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Driver's mirror	6.0%	3.6%	8.4%	7.8%	14.7%	11.6%	2.8%	11.0%
Rear mirror	4.7%	7.4%	4.0%	1.7%	4.5%	2.5%	6.3%	5.1%
Right mirror	7.1%	17.8%	2.7%	3.7%	13.4%	2.7%	19.3%	7.2%
Left Window	1.5%	0.2%	0.2%	0.2%	4.9%	1.3%	0.0%	0.0%
Right Window	3.0%	3.6%	0.1%	0.3%	5.1%	1.2%	4.6%	0.4%
Shifter	3.2%	0.7%	0.0%	0.4%	2.1%	0.3%	1.1%	0.1%
Left shoulder	21.6%	4.2%	27.3%	6.0%	14.0%	14.4%	5.2%	7.2%
Right shoulder	23.6%	47.0%	56.2%	78.2%	24.7%	62.7%	147.2%	167.3%

7.1.4 Glance Direction by Age

Means across tasks are also shown on Figures 7-2 and 7-3. There are several large differences between the young and elderly participants. Across all tasks the young participants look over their right shoulder 59.9% of the time and the elderly participants only look over their right shoulder 37.4% of the time while traveling in reverse. Elderly drivers are far more likely to use their mirrors than the young participants. Glances to the three mirror locations combined for about 34% of the older drivers' looking time, but only 15% or less than half as much, for younger drivers' looking. The breakdown of the glance direction by age group is shown below.

Table 7-3. Percent glance direction for all tasks between young and elderly participants.

Glance Direction	Young	Elderly
Forward	9.9%	11.8%
Dash	0.0%	0.0%
Driver's mirror	4.3%	15.0% **
Rear mirror	3.3%	7.1% **
Right mirror	7.7%	12.1%
Left Window	0.7%	1.5%
Right Window	2.1%	2.1%
Shifter	0.4%	1.8% **
Left shoulder	12.8%	12.3%
Right shoulder	59.9%	37.4% **

(** significant at the 0.05 level)

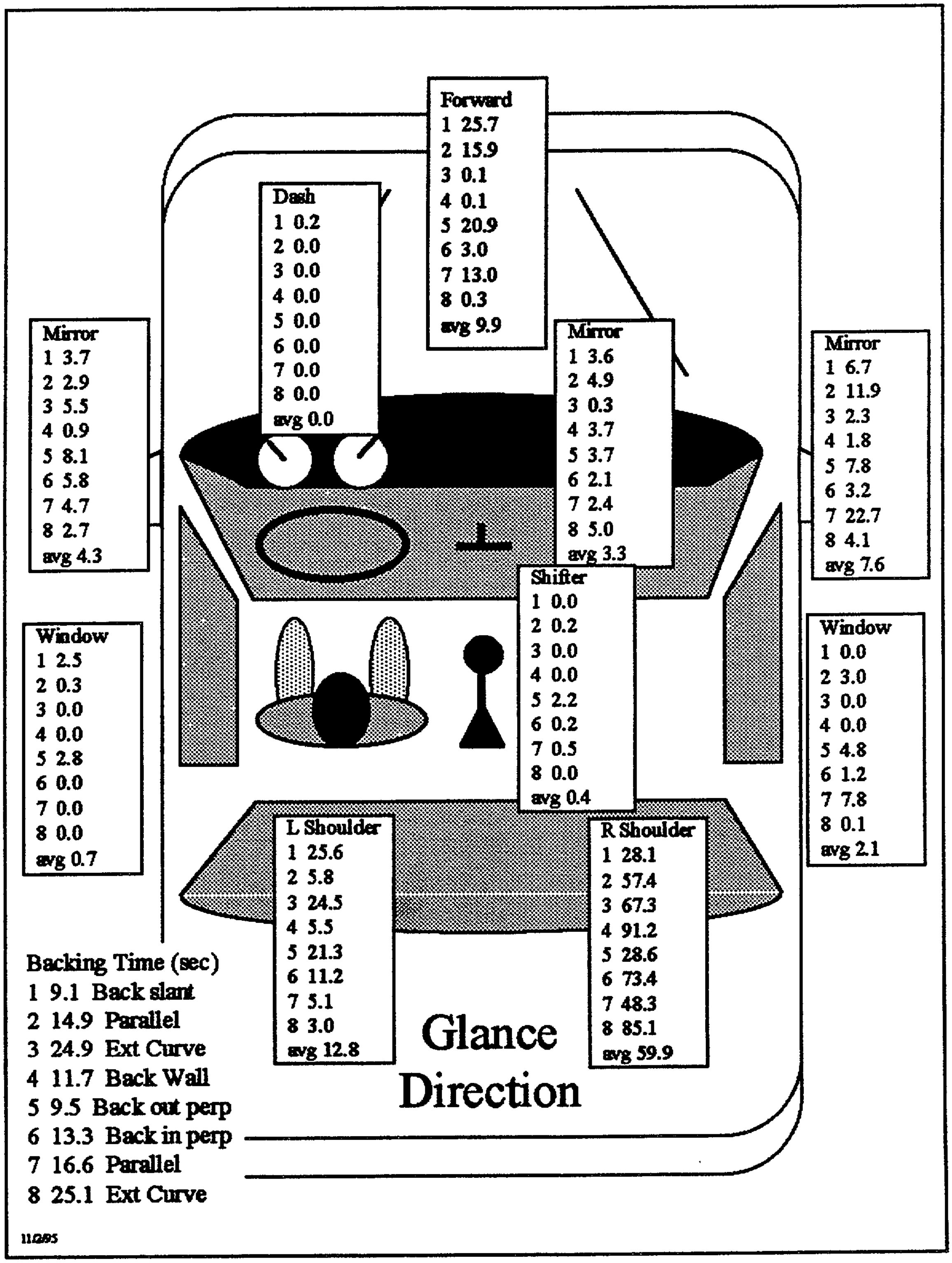

Figure 7.2 Average percent glance duration for all young subjects while moving backward, sorted by task.

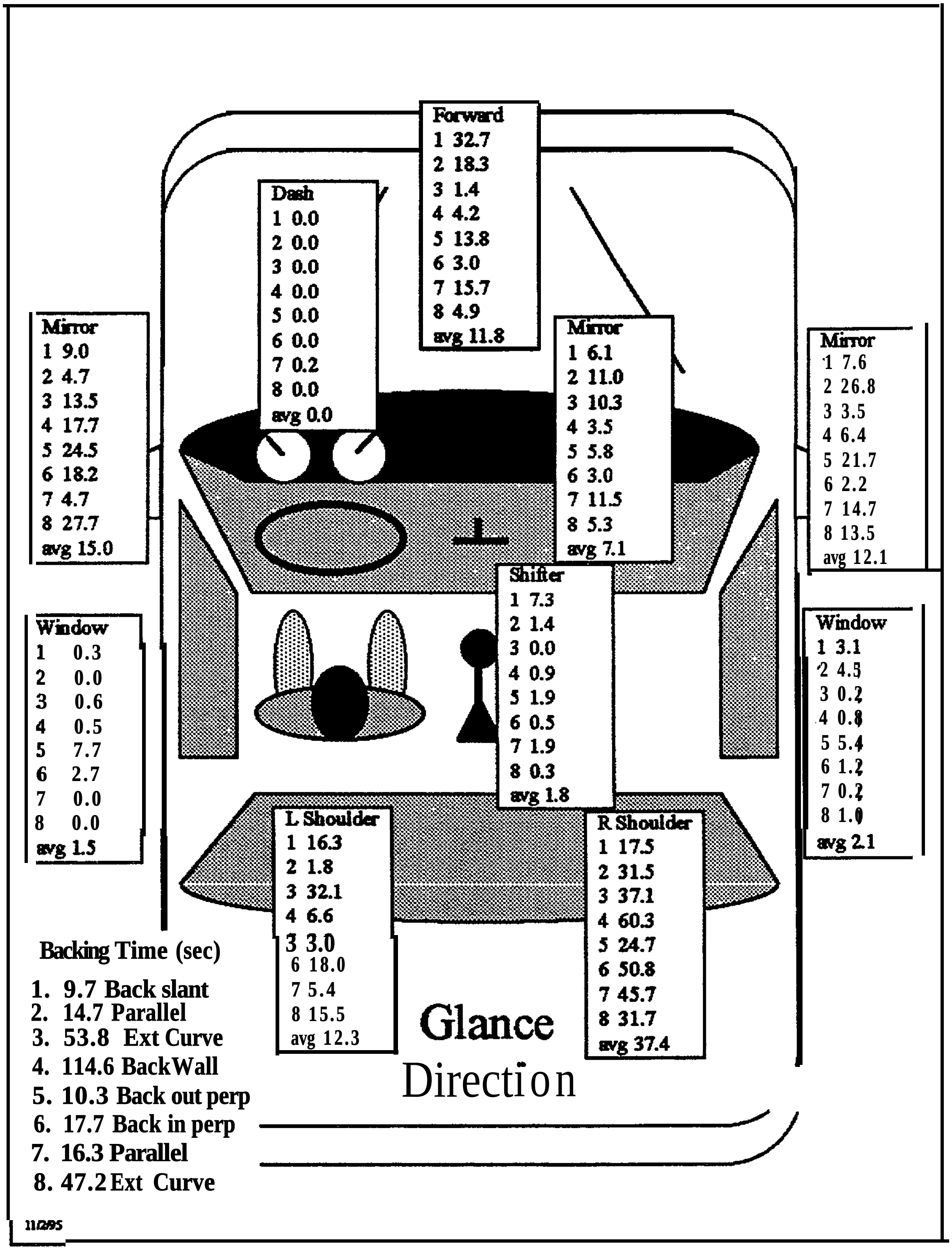

Figure 7.3 Average percent glance duration for all elderly while moving backward, sorted by task.

7.1.5 Glance Direction by Age and Task

Figures 7-2 and 7-3 show the breakdown of glance direction between the young participants and elderly participants on a task by task basis. Looking at the data task by task reveals several large differences. For example, for task 8 young participants looked over their right shoulders 85.1% of the time while elderly drivers only looked over their right shoulders 31.7% of the time (significant at 0.05 level). Tables 7-4 through 7-l 1 compare the young and elderly on each task.

Table 7-4. Percent glance direction between young and elderly participants for Task 1.

Glance direction	Young	Elderly
Forward	25.7%	32.7%
Dash	0.2%	0.0%
Driver's mirror	3.7%	9.0%
Rear mirror	3.6%	6.1%
Right mirror	6.7%	7.6%
Left Window	2.5%	0.3%
Right Window	2.9%	3.1%
Shifter	0.1%	7.3%
Left shoulder	25.6%	16.3%
Right shoulder	28.1%	17.5%

(none were significant at the 0.05 level)

Table 7-5. Percent glance direction between young and elderly participants for task 2.

Glance direction	Young	Elderly
Forward	15.9%	18.3%
Dash	0.0%	0.0%
Driver's mirror	2.9%	4.7%
Rear mirror	4.9%	11.0%
Right mirror	11.9%	26.8%
Left Window	0.3%	0.0%
Right Window	3.0%	4.5%
Shifter	0.2%	1.4%
Left shoulder	5.8%	1.8%
Right shoulder	57.4%	31.5% **

** (significant at the 0.05 level)

Table 7-6. Percent glance direction between young and elderly participants for task 3.

Glance direction	Young	Elderly
Forward	0.1%	1.4% **
Dash	0.0%	0.0%
Driver's mirror	5.5%	13.5%
Rear mirror	0.3%	10.3% **
Right mirror	2.3%	3.5%
Left Window	0.0%	0.6%
Right Window	0.0%	0.2%
Shifter	0.0%	0.0%
Left shoulder	24.5%	32.1%
Right shoulder	67.3%	37.1%

** (significant at the 0.05 level)

Table 7-7. Percent glance direction between young and elderly participants for task 4.

Glance direction	Young	Elderly
Forward	0.1%	4.2% **
Dash	0.0%	0.0%
Driver's mirror	0.9%	17.7% **
Rear mirror	3.9%	3.5%
Right mirror	1.8%	6.4%
Left window	0.0%	0.5%
Right window	0.0%	0.8%
Shifter	0.0%	0.9%
Left shoulder	5.5%	6.6%
Right shoulder	91.2%	60.3% **

** (signigicant at the 0.05 level)

Table 7-8. Percent glance direction between young and elderly participants for task 5.

Glance direction	Young	Elderly
Forward	20.9%	13.9%
Dash	0.0%	0.0%
Driver's mirror	8.1%	24.5% **
Rear mirror	3.7%	5.8%
Right mirror	7.8%	21.7%
Left window	2.8%	7.7%
Right Window	4.8%	5.4%
Shifter	2.2%	1.9%
Left shoulder	21.3%	3.0% **
Right shoulder	28.6%	18.8%

** (significant at the 0.05 level)

Table 7-9. Percent glance direction between young and elderly participants for task 6.

Glance direction	Young	Elderly
Forward	3.0%	3.0%
Dash	0.0%	0.0%
Driver's mirror	5.8%	18.6%
Rear mirror	2.1%	2.2%
Right mirror	3.2%	2.2%
Left Window	0.0%	2.7%
Right Window	1.2%	1.2%
Shifter	0.2%	0.5%
Left shoulder	11.2%	18.0%
Right shoulder	73.4%	50.8%

(none were significant at the 0.05 level)

Table 7-10. Percent glance direction between young and elderly participants for task 7.

Glance direction	Young	Elderly
Forward	13.0%	15.7%
Dash	0.0%	0.2%
Driver's mirror	1.3%	4.7%
Rear mirror	2.4%	11.5% **
Right mirror	22.7%	14.7%
Left Window	0.0%	0.0%
Right Window	7.8%	0.2%
Shifter	0.5%	1.9%
Left shoulder	5.1%	5.4%
Right shoulder	48.3%	45.7%

** (significant at the 0.05 level)

Table 7-l 1. Percent glance direction between young and elderly participants for task 8.

Glance direction	Young	Elderly
Forward	1.0%	14.2% **
Dash	0.0%	0.0%
Driver's mirror	2.7%	27.7% **
Rear mirror	5.0%	5.3%
Right mirror	4.1%	13.4%
Left Window	0.0%	0.0%
Right Window	0.1%	1.0%
Shifter	0.0%	0.3%
Left shoulder	3.0%	15.5%
Right shoulder	85.1%	31.7% **

** (significant at the 0.05 level)

7.1.6 Glance Direction by Gender

When considered across tasks, glance direction was very similar for males and females (Table 7-12).

Table 7-12. Percent glance direction between females and males across all tasks.

Glance Direction	Female	Male
Forward	10.9%	10.1%
Dash	0.1%	0.0%
Driver's mirror	11.7%	5.1% **
Rear mirror	6.3%	2.9% **
Right mirror	9.0%	9.2%
Left Window	1.1%	1.1%
Right Window	2.9%	2.0%
Shifter	1.5%	0.6%
Left shoulder	8.1%	16.6% **
Right shoulder	48.7%	52.7%

** (significant at the 0.05 level)

7.1.7 Glance Direction by Gender and Task

Glance direction was similar for males and females. In fact, when using T-test to compare performance task by task and glance direction by glance direction none of the results are significantly different at the p=0.05 level. A breakdown of each task shown below in Tables 7-13 through 7-20..

Table 7-13. Percent glance direction between female and male participants for Task 1.

Glance direction	Female	Male
Forward	29.6%	27.8%
Dash	0.2%	0.0%
Driver's mirror	9.6%	2.7%
Rear mirror	5.1%	4.3%
Right mirror	5.9%	8.1%
Left window	0.0%	2.9%
Right Window	4.0%	2.0%
Shifter	6.6%	0.1%
Left shoulder	15.9%	26.7%
Right shoulder	21.8%	25.2%

(none were significant at the 0.05 level)

Table 7-14. Percent glance direction between female and male participants for task 2.

Glance direction	Female	Male
Forward	19.5%	14.2%
Dash	0.0%	0.0%
Driver's mirror	3.3%	3.9%
Rear mirror	9.8%	4.9%
Right mirror	22.8%	12.9%
Left Window	0.2%	0.1%
Right Window	2.1%	5.1%
Shifter	0.0%	1.4%
Left shoulder	1.1%	7.3%
Right shoulder	43.9%	50.1%

(none were significant at the 0.05 level)

Table 7-15. Percent glance direction between female and male participants for task 3.

Glance direction	Female	Male
Forward	1.1%	0.0%
Dash	0.0%	0.0%
Driver's mirror	12.5%	3.8%
Rear mirror	6.6%	1.1%
Right mirror	3.8%	1.6%
Left Window	0.0%	0.5%
Right Window	0.0%	0.0%
Shifter	0.0%	0.0%
Left shoulder	18.7%	37.0%
Right shoulder	57.1%	55.2%

(none were significant at the 0.05 level)

Table 7-16. Percent glance direction between female and male participants for task 4.

Glance direction	Female	Male
Forward	1.9%	1.7%
Dash	0.0%	0.0%
Driver's mirror	15.2%	1.0%
Rear mirror	1.6%	1.8%
Right mirror	4.2%	3.3%
Left Window	0.4%	4.9%
Right Window	0.2%	0.5%
Shifter	0.2%	0.5%
Left shoulder	4.2%	7.6%
Right shoulder	72.2%	83.6%

(none were significant at the 0.05 level)

Table 7-17. Percent glance direction between female and male participants for task 5.

Glance direction	Female	Male
Forward	14.7%	20.8%
Dash	0.0%	10.0%
Driver's mirror	21.4%	9.2%
Rear mirror	7.4%	2.2%
Right mirror	11.9%	14.5%
Left window	4.8%	4.9%
Right window	4.9%	5.2%
Shifter	1.8%	2.4%
Left shoulder	11.4	16.1%
Right shoulder	22.2%	26.7%

(none were significant at the 0.05 level)

Table 7-l 8. Percent glance direction between female and male participants for task 6.

Glance direction	Female	Male
Forward	4.5%	1.8%
Dash	0.0%	0.0%
Driver's mirror	11.5%	11.8%
Rear mirror	5.0%	0.7%
Right mirror	0.0%	4.7%
Left Window	3.0%	0.0%
Right Window	2.5%	0.2%
Shifter	0.2%	0.4%
Left shoulder	11.3%	16.7%
Right shoulder	61.2%	63.8%

(none were significant at the 0.05 level)

Table 7-19. Percent glance direction between female and male participants for task 7.

Glance direction	Female	Male
Forward	14.5%	13.7%
Dash	0.2%	0.0%
Driver's mirror	1.6%	3.9%
Rear mirror	7.3%	5.4%
Right mirror	16.2%	22.0%
Left Window	0.0%	0.0%
Right Window	9.2%	0.3%
Shifter	2.1%	0.2%
Left shoulder	1.2%	8.9%
Right shoulder	47.6%	46.8%

(none were significant at the 0.05 level)

Table 7-20. Percent glance direction between female and male participants for task 8.

Glance direction	Female	Male
Forward	2.5%	1.3%
Dash	0.0%	0.0%
Driver's mirror	18.2%	4.8%
Rear mirror	7.5%	3.0%
Right mirror	7.4%	7.1%
Left Window	0.0%	0.0%
Right Window	0.1%	0.6%
Shifter	0.0%	0.2%
Left shoulder	0.8%	12.7%
Right shoulder	63.8%	70.3%

(none were significant at the 0.05 level)

7.1.8 Glance Direction When Starting to Back Up

Of particular importance is the glance direction when the driver first starts to backup. The breakdown of the glance direction upon initial backup (time=0) is shown in Table 7-21 below.

Table 7-21. Breakdown of glance direction at t=0 for all participants.

Glance Direction	Time=0(count)	Time=0(%)
0 - forward	10	6.4
1 - driver's mirror	9	5.8
2-rear mirror	10	6.4
3 - right mirror	6	3.9
4 - right window	3	1.9
5 - left window	0	0.0
6-dash	0	0.0
7 - shifter	7	4.5
8 - right shoulder	89	57.1
9-left shoulder	22	14.1

The following table (7-22) lists the count broken down by age across all tasks. In this table the number of trials are for the elderly (n = 64) and for the young (n = 92).

Table 7-22. Glance direction at t=0 for elderly and young participants.

Glance **Direction**	**T=0 (count(%) elderly)**	**T=0 (count (%) young)**
0 - forward	7 (10.9%)	3 (3.3%)
1-driver's mirror	7 (10.9%)	2 (2.2%)
2-rear mirror	8 (12.5%)	2 (2.2%)
3 - right mirror	3 (4.7%)	3 (3.3%)
4 - right window	2 (3.1%)	1 (1.1%)
5 - left window	0 (0.0%)	0 (0.0%)
6- dash	0 (0.0%)	0 (0.0%)
7 - shifter	6 (9.4%)	1 (1.1%)
8 - right shoulder	25 (39.1%)	64 (69.7%)
9 - left shoulder	6 (9.4%)	16 (17.4%)

The following table (7-23) shows the glance direction exactly one second into the backing sequence for all participants.

Table 7-23. Glance direction at t= 1 for all participants.

Glance Direction	**Time = 1 (count)**	**Time = 1 (%)**
0 - forward	**9**	**5.8**
1 - driver's mirror	**6**	**3.9**
2 - rear mirror	**8**	**5.2**
3 - right mirror	**7**	**4.6**
4 - right window	**3**	**1.9**
5 - left window	**1**	**0.6**
6 - dash	**0**	**0.0**
7 - shifter	**1**	**0.6**
8 - right shoulder	**92**	**59.7**
9 - left shoulder	**27**	**17.5**

The following table (7-24) shows the breakdown for glance direction at one second into the backing sequence by age across all tasks.

Table 7-24. Glance direction at t= 1 for elderly and young participants.

Glance Direction	T=1 (count (%) elderly)	T=1 (count (%) young)
0 - forward	6 (9.4%)	4 (4.4%)
1 - driver's mirror	3 (4.7%)	2 (2.2%)
2 - rear mirror	7 (10.9%)	1 (1.1%)
3 - right mirror	4 (6.2%)	4 (4.4%)
4 - right window	2 (3.1%)	1 (1.1%)
5 - left window	0 (0.0%)	1 (1.1%)
6 - dash	0 (0.0%)	0 (0.0%)
7 - shifter	1 (48.4%)	0 (0.0%)
8 - right shoulder	31 (48.4%)	66 (71.7%)
9 - left shoulder	10 (15.6%)	13 (14.1%)

7 3 Backing Speed

The speed at which people back up is analyzed in the following sections.

7.2.1 Maximum Backing speed by Participant and Task

There was a wide variation of maximum backing speeds between tasks and participants. The breakdown of each participant's maximum backing speed is shown in Appendix C. For example, Table 7-25 shows the maximum backing speeds for two participants.

Table 7-25. Maximum backing speed (MPH) for two participants by task

Task	Participant 3	Participant 7
1. Back Angle	3.1	3.1
2. Parallel	2.1	**4.1**
3. Extended curve	**4.5**	**7.4**
4. Back wall	**2.7**	**4.4**
5. Back out perp	3.1	**3.3**
6. Back in perp	**3.1**	**3.0**
7. Parellel	1.8	**4.2**
8. Extended curve	8.0	13.5

7.2.2 Maximum Backing Speed bv Task

Maximum backing speeds varied greatly between tasks. The mean maximum speed, minimum maximum speed and the maximum maximum speed while backing for each task are shown in the table beiow (7-26).

Table 7-26. Backing speeds (MPH) for all participants

Task	Avg Max	Min Max	Max Max
1. Back Angle	3.0	1.5	6.3
2. Parallel	2.9	1.2	6.7
3. Extended curve	6.7	2.5	12.2
4. Back wall	3.5	1.9	5.9
5. Back out perp	3.3	2.0	7.0
6. Back in perp	2.9	1.4	4.6
7. Parallel	2.8	1.7	5.4
8. Extended curve	10.0	4.5	14.8

7.3.3 Maximum Backing Speed by Age and Task

The maximum backing speed for each age group broken down by task is shown below. On several of the task the younger drivers had significantly faster maximum speeds while backing.

Table 7-27. Maximum backing speed (MPH).

Task	Young	Elderly
1. Back Angle	3.4	2.5
2. Parallel	3.5	2.1 **
3. Extended curve	8.3	4.0 **
4. Back wall	3.8	3.1
5. Back out perp	3.7	2.6
6. Back in perp	3.1	2.6
7. Parallel	3.0	2.5
8. Extended curve	11.6	7.0 **

(** significant at the 0.05 level)

7.3.4 Maximum Backing Speed by Gender and Task

The maximum backing speed for each gender broken down by task is shown below. Male drivers had faster maximum backing speeds on 7 of the 8 tasks. On two of the tasks the difference was significant,

Table 7-28. Maximum backing speed (MPH).

Task	Females	Males
1. Back Angle	2.9	3.1
2. Parallel	2.6	3.2
3. Extended curve	5.6	7.9
4. Back wall	3.0	4.0 **
5. Back out perp	3.2	3.3
6. Back in perp	2.4	3.6 **
7. Parallel	2.5	3.1
8. Extended curve	10.1	10.0

(** significant at the 0.05 level)

7.3.5 Sample Velocity Profiles

In this experiment there were 21 participants each doing 8 different backing tasks. Therefore, there are 168 backing profiles. There was great variety in the profiles of velocity. Examples of sample velocity profiles can be found in Appendix D.

Glance-Hand-Velocity vs. Time

The example is for subject 1 task 4 (back to wall).

Unlike the other graphs the Glance-Hand-Velocity vs. Tie graph shows the complete task not just the part of the task where the car is moving in reverse. The sign of the velocity indicates the direction. Positive velocities represent moving forward, negative velocities represent reverse, and zero velocity means the car is stopped. The glance direction and hand position are represented using codes. The value of the codes are shown below the graph. This graph starts out with the subject's right hand on the steering wheel (code 3). The hand then moves to shift to reverse (code 2) then back to the steering wheel (code 3). The glance direction starts looking forward (code 0), moves to the right window(code 4), then to the left window (code 5), back to the right window(code 4), and then to the shifter (code 7). Since all three parameters are plotted on the same time axis it possible to better understand the time sequence of glance and hand positions as the task progresses and the vehicle changes velocity.

7.3 Time To Collision (TTC)

The following analysis examines the TTC. TTC at any point of the backing sequence is calculated by assuming constant velocity over the remaining distance to the target. TTC is examined across all participants and by age and gender breakdowns. Only four of the tasks had TTC values since there was no object behind the vehicle in four of the tasks.

7.3.1 Minimum TTC by Participant by Task

The minimum TTC for each participant on each task is shown in appendix D. There are large individual differences. Example times for two participants are shown below (in seconds).

Table 7-29. Minimum TTC for Subjects 9 and 10

Task	Min TTC sub 9	Min TTC sub 10
2. Parallel	4.5	2.6
4. Back Wall	2.7	1.1
6. Back in Perp	1.7	3.2
7. Parallel	4.1	6.3

7.3.3 Minimum Time-to-Collision (TTC) by Task

The minimum TTC (in seconds) for each task across all participants is shown below

Table 7-30. Minimum TTC for All Subjects

Task	Min Min	10th percentile	Avg Min	Max Min
2. Parallel	1.0	1.3	3.4	6.3
4. Back Wall	1.1	1.5	2.4	3.9
6. Back in Perp	1.7	1.9	3.0	4.3
7. Parallel	2.0	2.1	3.7	6.3

7.3.3 Minimum TTC by Age and Task

The age breakdown of TTC by task is shown below. Minimum TTC for the young and elderly are not statistically different. (in seconds)

Table 7-3 1. Minimum TTC by Age and Task

Task	Elderly	Young
2. Parallel	3.4	3.4
4. Back Wall	2.6	2.5
6. Back in Perp	3.2	3.0
7. Parallel	4.2	3.4

(none were significant at the 0.05 level)

The gender breakdown of TTC by task is shown below. Minimum TTC for the males and females are not statistically different. (in seconds)

Table 7-32. Minimum TTC by Gender

Task	Female	Male
2. Parallel	3.6	3.2
4. Back Wall	2.5	2.5
6. Back in Perp	3.1	3.0
7. Parallel	4.1	3.2

(none were significant at the 0.05 level)

7.3.4 Sample TTC Graphs

Appendix D contains graphs which show the relation of glance direction, hand position, and velocity to time. This appendix also contains sample graphs of TTC versus time and the relation of TTC, distance, and velocity to time.

TTC vs. Time
The example is the TTC vs Tie Graph for Subject 3 Task 4 (back to wall).

Description of the graph - The TTC vs Tie graph for Subject 3 Task 4 is an example of a typical TTC vs. Tie graph. The graph shows how the time to collision varies as the subject backs to the wall. This graph only display data when the car is travelling in reverse. No data is shown when the car is stationary or moving forward. TTC vs. Tie graphs have a characteristic shape as shown in the example graph. The TTC is very high as the car first starts to move, but rapidly levels out and stays constant until the car starts to slow down and stop. Subject 3 maintains a TTC of between 5 and 7.5 seconds over the majority of the backing maneuver.

TTC-Distance-Velociry vs. Time
The example is the TIC-Distance-Velocity vs. Tie graph for Subject 3 task 4 (back to wall)

Description of the graph - This graph shows the variation of three parameters over the backing sequence. The three variables that are plotted are the distance to the wall, the time to collision with the wall, and the car's velocity. The velocity is shown as a negative value since the car is moving in reverse during the time frame shown on the graph. The relationships between the variables are easily observed from this graph. The distance decreases asymptotically as the car approaches the wall, The velocity slowly decreases over the majority of the task maintaining a constant TTC.

TTC-Vavg vs. Distance
The example is the TTC-Vavg vs. Distance graph for subject 3 task 4 (back to wall)

Description of the graph - The TTC-Vavg vs. Distance graphs differ from the other graphs in that distance (to the wall) instead of time is plotted on the abscissa. Since the subject is backing to a wall, time is moving from right (large distances) to left (small distances) along the abscissa. This graph permits the examination of how the velocity and TTC change with the distance to the wall. For the example shown, the TTC is relatively flat over the task while the velocity (shown as negative since in reverse) declines steadily over the range from 30 feet to the stopping point.

7.4 Time versus Distance

For each backing trial, a time versus distance plot was generated. This graphically illustrates the distance traveled in a given time from initiation of movement, or conversely, the time elapsed before the vehicle traveled a given distance. These plots are shown in Appendix E. The data are organized by site, with the data for all subjects plotted on a single chart for a given site. These plots make it immediately apparent how far most or all drivers travel in the first few seconds after they initiate backing. This information will be of general interest for the study of backing maneuvers, and may have particular significance for helping to set warning criteria. The time to collision data suggest that TTC might be a particularly effective parameter for defining when a warning is necessary, since drivers tend to maintain a relatively stable TTC However, TTC is not a meaningful measure at the start of a backing maneuver. For example, if an object was only a few inches behind a vehicle, TTC would be infinitely large at the start of the maneuver (since speed is 0), yet it would be desirable to give an immediate warning. Knowing how far drivers back at various times after the start of the maneuver could be useful in defining criteria for warnings as backing begins.

Excluding Site 8, which is discussed below, backing looks rather similar over the first couple of seconds of each maneuver. Most drivers back no more than 2 to 3 feet in the first 1.0 second, although outlier subjects may travel 4 feet. After 1.5 seconds, most travel no more than 3.5 to 4 feet, although a few outliers may travel 6 to 7 feet. After 2.0 seconds, most drivers have gone no more than 5 to 8 feet, although a few may have gone 9 to 11 feet. The slowest initial backing occurred for backing out of an angle slot in a parking garage, and probably reflects caution to the threat of difficult-to-see vehicles. The similarity among the sites is noteworthy, given the variety of the maneuvers and features. Traveling 3 feet per second is equivalent to a speed of about 2 mph. Five feet per second (roughly typical for the interval between 1.0 and 2.0 seconds of travel) equates to about 3.4 mph.

The exception to this pattern of similarity is Site 8, which was an extended curvilinear backing maneuver. The envelope of distances is roughly 50% broader. Many drivers traveled 3 to 4 feet in the first 1.0 second, 6 to 7 feet in 1.5 seconds, and 12 feet in 20. seconds. One extreme subject went substantially faster (6 feet in 1 .O second, 12 feet in 1.5 seconds, and 18 feet in 2.0 seconds; this means that the speed attained for this most extreme driver, between 1.0 to 2.0 seconds after starting, was about 8 mph). The reason for this site being so discrepant is not known, although we speculate that it is due to the fact that it was somewhat uphill, in addition to beiig spatially extended. Drivers may have tended to use the accelerator more to initiate travel, rather than just releasing the brake at idle speed, due to the incline. However, since the various sites differed in numerous ways, this is speculative.

8.0 CONCLUSIONS

Conclusions are broken down into the following categories:

- Glance direction
- Maximum backing speed
- Minimum time-to-collision (TTC)
- Time versus distance
- Summary

8.1 Glance Direction

This study produced a wealth of glance data. At the most general level the question answered is where people look when they are backing up. When looking across all participants and tasks it is apparent that the glance direction is distributed in many directions while backing. Participants spent about half of their backing time looking over their shoulder out the back of the vehicle. Of particular interest is that for the tasks used in this study people looked forward 10.6% of the time while backing. Looking across tasks the percentage of time that people looked forward while backing up varied from 28.7% on Task 1 (backing out of an angled slot) to 0.6% on task 3 (extended curved backing). This has major implications for the design of backup warning systems. If a visual warning display is used it must also be viable when the driver is looking forward, out the side windows, over the right and left shoulders, and in all the mirrors or there will be a likelihood that it will be missed.

The task and driver age had a major influence on glance direction. Task differences were particularly dramatic. Tasks that had relatively slow speeds and required a fairly complex backing sequence (e.g., parallel parking) tended to have glances distributed more evenly around the vehicle. Tasks that had high speeds and did not require precise placement of the vehicle (extended curved backing) tended to have glance focused in one direction (backward over the shoulder).

The age of the driver had a large influence on glance direction. In general, older drivers were far less likely to look over their right shoulder. This difference was compensated for by looking at their mirrors (left shoulder glance durations were about the same for the young and elderly). The reason for this difference is not known, although it is likely that the older drivers lacked flexibility to look over their shoulders so they used a less demanding posture of looking in the mirror whenever possible. Comparing on a task-by-task basis revealed a number significant differences between the young and elderly.

Unlike age differences which were abundant between tasks, there were not significant differences between males and females with respect to glance direction on a task by task comparison.

Analyzing the glance direction at the begin&g of the backup sequence revealed a major difference between the elderly and the young, The young participants were looking backwards over either shoulder 87.0% of the time while the elderly were only looking over their shoulders 48.5% of the time. It also appeared that the elderly were looking in less appropriate directions (at the shifter 9.4% and forward 10.9%) far more often than the young (shifter = 1.1% and forward = 3.3%) at the start of the backing sequence. If the start of the backing is a time of higher danger of pedestrian accidents (as seems likely) then the elderly may be more likely to have accidents during thii period since their attention is not focused on the direction of the vehicle. In these situations a backing warning system would be potentially beneficial especially for the elderly.

8.2 Maximum Backing Speed

As expected the maximum backing speed varied greatly between tasks. Typical parking lot types of tasks (all tasks except extended curved backing) all had slow maximum maximum backing speeds (less than 7.0 mph, 10.3 fps). The mean maximum backing speed for these tasks was around 3.0 mph (4.4 fps) There tended to be large individual differences in backing speed between participants. Some people are very cautious while others back up much faster.

The young driver's average maximum backing speed was faster than the elderly driver's on every task and it reached statistical significance on three of the tasks (task 2 parallel, task 3 extended curved, and task 8 extended curved).

The male driver's mean maximum backing speed was generally faster than the females and reached statistical significance on two of the tasks (task 4 backing to a wall and task 6 backing into a perpendicular parking slot).

8.3 Time to Collision

The time to collision measure can be viewed as a risk measure. TTC is the time that drivers have to *react* and stop their vehicle. The smaller the TTC, the higher the risk to the driver. When examining the TTC graphs it is apparent that drivers tend to keep the TTC fairly constant over a large part of the backing sequence. As the they approach a target, drivers tend to slow down in such as way as to keep the TTC constant. It appears that the drivers compute the TTC and act to keep it at a comfortable range during backing.

Intuitively one would expect participants with a higher maximum backing speed to have smaller (more dangerous) TTC values. However, this was not the case in this experiment. As dii above young drivers had faster maximum backing speeds than the elderly. However, the minimum TTC values for the younger drivers were not statistically different from the older drivers. This implies that the young drivers were more efficient at backing. They were able go faster without experiencing any more risk as measured by TTC.

Likewise male drivers had statistically faster maximum backing speeds on two of the tasks when compared to female drivers. Like the young and the elderly the males and females did not have statistically different minimum TTC values. It appears that male drivers were able drive faster, but not incur any more risk as measured by TTC.

The 10th percentile values are also provided for TTC. These values may be useful when designing backup warning systems, to help define a threshold that will prevent accidents and keep false alarms to a minimum. The data suggest that any TTC less than 1.0 second, and generally less than 1.5 seconds, is likely to represent a driver error and should certainly trigger a warning. The virtue of extending the TTC warning criterion beyond 1.5 seconds will depend upon assumptions regarding brake reaction time while backing.

8.4 Time Versus Distance

Generally, drivers traveled no more than 2 to 3 feet in the first second of backing, and 5 to 8 feet after 2 seconds. A few outlier subjects traveled 4 to 6 feet in the first second, and up to 11 feet after 2 seconds. Although this performance typified seven of the sites, one site (Site 8, extended backing) did show roughly 50% greater typical travel distances in the first second or two of backing. These findings can be related to the need to alert drivers to the presence of objects behind the vehicle at the time they put the vehicle in reverse gear and/or begin backward movement. Appropriate warning criteria will depend to a certain degree upon assumptions about brake reaction time (for which objective data are lacking). The data suggest that objects within about 5 feet should be immediately warned about (although a transient warning would be most appropriate to reduce inappropriate alarms). Additionai cautionary warnings might be appropriate for targets up to 10 feet away. Objects beyond 10 feet are usually well over 2 seconds (usually exceeding 2.5 seconds) away, and probably could be adequately warned about by measures based on TTC.

8.5 Summary

This experiment provided a wealth of information about how people back up in a naturalistic setting. A wide range of drivers were observed (old and young, male and female) performing a wide variety of backing tasks. All drivers used their own vehicles and drove on public streets. Patterns of glance, hand position, velocity, and distance to targets were all measured as the driver performed eight backing tasks. The data collected in this experiment provides baseline data that can be used in the design of backing warning systems, parking lots, vehicle mirrors, vehicle windows, and special purpose devices for the elderly.

The major findings in this experiment are summarized below:

a. Glance direction while backing varied greatly by task

b. Glance direction while backing varied greatly by age (elderly vs young); older drivers showed more mirror use and less looking over the right shoulder

c. There was little difference in glance direction between males and females

d. Glancing over the right shoulder was the most frequent location, at the initiation of backing and overall

e. Except for extended backing maneuvers, maximum backing speeds averaged around 3 mph, and did not exceed 7 mph

f. Maximum backing speed was generally faster for the young vs. the elderly

g. Male drivers tended to back faster than female drivers

h. TTC typically dropped to an asymptotic value as the vehicle approached an object, and remained relatively stable as the vehicle slowed while approaching

i. Minimum TTC's were greater than 1.0 second, and usually exceeded 2.0 seconds

j. TTC values did not vary for males and females

k. TTC values did not vary for young and elderly

1. Drivers typically traveled less than 3 feet in the first second of backing, and usually less than 8 feet after two seconds.

APPENDIX A: FORMS

INFORMED CONSENT FORM

REAR DETECTION RESEARCH STUDY

Purpose of the Research: The purpose of this research is to collect information about the performance of a vehicle dynamics monitoring system at detecting and accurately measuring use and performance parameters of various vehicles. This information will include (1) computerized collection of vehicle dynamics and driver interactions, and (2) videotaped observation of the vehicle and roadway for use in interpreting the data. The reason for doing this study is to provide design recommendations to the government and researchers that typically use these types of systems for on-road driving research.

Research Procedures: A set of video cameras and some specialized measurement sensors will be installed on your vehicle and recording equipment will ride in your trunk during this exercise. The purpose of the equipment is to record the data from these sensors as you drive. You will then simply drive, with the investigator as a passenger, in your normal manner along a route specified by the investigator. The drive will include a variety of driving situations including residential, suburban and city locations as well as several parking lots. This will allow us to put this sensor system through a variety of situations including forward and backward motion that should demonstrate how well it works. The investigator will stay out of your way in the back seat during all of the driving and will lie down in the back seat when you have to back up so that he/she doesn't obstruct your vision in any way. We want you to simply drive in your typical fashion. There are a number of places that we would like to have you visit along the route. The investigator will give you instructions along the way to ensure that you get to all of them,

Once the video system is installed on your vehicle, the entire drive should take about 45 minutes. The full session, including the installation and removal of the video system, will take less than two hours. You will be paid $40 for your participation in this study.

Foreseeable Risks: You will be asked to drive your own vehicle in your normal manner over normal roads, along a route specified by the investigator. Therefore the risks are those inherent in normal driving and parking. You will not be asked to drive in any unusual or illegal manner. You and the investigator (passenger) will be required to wear seat belts. Generally you will be driving on regular public roadways and stopping in parking spots or lots.

In the course of your drive, you may expect to encounter other traffic and events that can occur in everyday driving and parking situations. There will be no collision hazards other than what you encounter in normal driving and parking in traffic If, for any reason, you do not feel comfortable driving or parking where the investigator asks you to go, let him/her know and we will accommodate you as much as possible. It is your responsibility to let the investigator know of this discomfort. Do not perform any maneuver that makes you feel uncomfortable or unsafe. YOU ARE DRIVING AT YOUR OWN RISK.

Benefits of the Research: The findings of this study will be used to evaluate the adequacy of this vehicle dynamics monitoring system. As a result of the research, design standards or recommendations for future systems could be changed. This could result in improved safety for the driving public through more effective research. Your only personal benefit will be in the form of cash compensation for participation,

Confidentiality: We will be asking you for some basic descriptive information about yourself. This includes your age, your driving history and habits (how long have you been driving, how much do you drive, etc.), and certain questions about physical status or health that may relate to driving (your vision, arthritic difficulties in turning your head, medicines that may affect driving, etc.). This information is important in helping us to interpret the research findings. This information is confidential, and no published reports of the research will identify any participants. Likewise, all information collected during the driving trip is confidential and will not be presented in any form that identifies individuals.

Contact Person: If you have questions about the research or the rights of research participants, contact Mr. Richard Huey, Lead Investigator, or Dr. Neil Lemer, Project Director, COMSIS Corporation, 8737 Colesville Road, Silver Spring, MD 20910; telephone (301) 588-0800. If you feel that your rights have been violated by the researcher, you may contact Mr. Mark Roskin, Chairman of the COMSIS Institutional Review Board, at the same address and phone number.

Voluntary Withdrawal from the Experiment: Your cooperation in this study is entirely voluntary. You may withdraw participation at any time. If you withdraw from the study, you will be paid on a prorated basis for the time you did participate.

Acceptance of Responsibility: As a volunteer you agree to accept full responsibility for any injury resulting from the risks associated with the study described in this consent form. Such acceptance does not waive your legal rights, nor does it remove COMSIS' liability for negligence.

AUTHORIZATION: I have read the above and recognize the risks of this study. I agree to participate as a participant in the research. I understand that participation is voluntary and I may withdraw from the study at any time. I have received a copy of this consent form for my records I accept full responsibility for driving in a safe and legal manner during this experiment. That is, I AM DRIVING AT MY OWN RISK.

Signature of Participant: ________________________________ Date: ________

Signature of Investigator: ________________________________ Date: ________

Drivers License Number: ________________________________

Vehicle Insurance Company Name: ____________________________________

Policy Number: ________________ Expiration Date: ____________

Session Debriefing Form

Name: ______________________________ Date of Birth: ______/______/______

Address: ____

Phone: ( ) - __________ Gender: M / F

What do you think this study was investigating? ________________________________
____

How were the driving situations we exposed you to today different from your daily routines?
____
____
____

Do you have a specific habit, philosophy, or rule that you typically follow when you back up?
____
____
____

What can you tell me specifically about your philosophy (during backing) regarding:

mirror use ____
____

head turning ____
____

speed ____
____

hand/foot position - ____
____

parking goals - ____
____

avoided maneuvers - ____
____

problems encountered (during study or in day-to-day driving) - __________________
____

If you were developing a device to aid backing, what would you particularly want in the design?
____
____

Would having such a device make it easier for you to drive or likely that you would drive more?
____
____

INSTRUCTIONS

You will be taking part in a study conducted by COMSIS Corporation for the U.S. Department of Transportation. We are going to be evaluating different kinds of devices and techniques for measuring what a vehicle is doing. Your vehicle will be outfitted with devices that record speed, or pedal position, or various distances, and so forth. We want to test how well different kinds of devices work for measuring various kinds of driving. This experiment is an evaluation of those devices, not a test of your driving. What is most important to us is that you just drive in your normal manner. If you do that, we will be able to see if the devices measure things properly. I will be asking you to drive around various places, and go through a number of backing up and parking maneuvers as well as typical driving in urban, residential and suburban settings around the Silver Spring area.

I will be asking you to drive around with this system for a few minutes while I collect the output from it and a more accurate calibration system running in parallel. The drive will include some residential, suburban, and city driving. It will also include various kinds of parking lot, driveway and on-street parking situations with some backing up required. Will you be comfortable with that kind of driving? [if not, stop here and dismiss participant]

After we go over the instructions and necessary forms, I will install the equipment for the study on your vehicle. The bulk of it fits in your trunk with small wires running from there to the sensors or the back seat where I'll be sitting. The sensors will need to be installed both inside and outside of your vehicle. We will be collecting four different video views, including one from directly in front of you looking back at you and over your right shoulder to get the full view of the rear situation. We will also be installing three very thin sensors on your brake and gas pedals and on your shift to get an idea about when you are braking, shifting or accelerating at any point in time with respect to the other sensor data. All of sensors except these thin pressure sensors will be installed with suction cups. We have used this method before with excellent success and there should be absolutely no damage to your vehicle from this mounting system.

I will be guiding you around a predefmed route that takes us through a variety of driving situations including city, residential and suburban areas within Silver Spring. I will give you plenty of notice before stops and turns. If for some unforeseen reason I don't give you enough notice to turn or stop at a given location, just go on by. We will not get lost and there is no penalty fo rhaving to turn around in a safe place and come back to a site.

I want to stress that you should drive just as you normally would. We want to use this system in typical driving situations, so you must drive in your normal fashion in order to adequately test it. I will try to be vry clear in the way that I describe each driving. maneuver that I want you to complete to avoid confusion. However, if you are unsure about any instruction I give you or do not feel comfortable performing it, please let me know and we will try to work around it. You should not perform any maneuver that you feel unsafe about. There are no times during this route that you should be in any dangerous situations unlike those you might encounter in normal driving situations.

OK? If you still feel that you want to participate, I will get started with the installation of the equipment on your vehicle. It should take me about 50 minutes to get everything hooked up. You may either stay here to watch or go into the COMSIS building for a few minutes to have a seat and a cool drink or cup of coffee while I get started. I need you to return here in about 45-50 minutes.

REAR DETECTION STUDY RECRUITMENT FORM

Hello, Mr./Mrs. ,this is with COMSIS Corporation here in Silver Spring. I believe that you participated in one of our recent studies and we thought you might be interested in being a part of the most recent one which is evaluating a new product development. Do you think you might be interested? If NO: OK, thank you for your time.

If YES: The purpose of this research is to collect information about the performance of a new vehicle dynamics monitoring system for the U.S. Department of Transportation. We will be looking at its ability to detect and accurately measure use and performance parameters of various vehicles. This information will include (1) computerized collection of vehicle dynamics and driver interactions, and (2) videotaped observation of the vehicle and roadway for use in interpreting the data. The reason for doing this study is to provide design recommendations to the government and researchers that typically use these types of systems for on-road driving research. A set of video cameras and some specialized measurement sensors will be installed on your vehicle and recording equipment will ride in your trunk during this exercise. The purpose of the equipment is to record the data from these sensors as you drive. You will then simply drive, with the experimenter as a passenger, in your normal manner along a route specified by the experimenter. The drive will include a variety of driving situations including residential, suburban and city locations as well as several parking lots. This will allow us to put this sensor system through a variety of situations including forward and backward motion that should demonstrate how well it works. We want you to simply drive in your typical fashion. There are a number of places that we would like to have you visit along the route. We would like to try it out in a variety of driving situations and with a number of different vehicles and drivers to see how it performs. The whole evaluation takes about 21/2 hours and we pay you $40 for your time. We will use suction cups for quick, safe attachment of our equipment to your vehicle and a small amount of power will be drawn from your cigarette lighter to run the system. Are you still interested in participating? If NO: OK, thank you for your time.

If YES: OK, we will need to verify a few things about you and your vehicle and set up a time when we can have you come in for the drive:

REQUIREMENTS (Check each upon verifying):

- Working cigarette lighter
- Rack seat for experimenter to ride in
- Trunk empty to put equipment in
- Current driver's license and insurance
- Willing to drive around Silver Spring
  (city, suburban, and residential areas)
- Capable of performing most typical driving maneuvers
  (i.e., merging, stopping, turning, backing, parking, etc.)

Timing:
Meet:
Finish Install:
Finish Route:
Dismiss:

Name: Phone: ( )
Address:
Date of Birth: / /
Gender: Male / Female Years of driving: