Using an Automated Speed, Steering, and Gap Control System and a Collision Warning System When Driving in Clear Visibility and in Fog

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FOREWORD

This report presents the results of one of a series of experiments that investigated driver performance in a generic Automated Highway System (AHS) configuration. The experimental research was conducted in an advanced driving simulator and investigated the effects of using an automated speed, steering, and gap control system (SSGCS) and a collision warning system (CWS) on driving behavior. When either the SSGCS or the CWS was on alone, it had no effect on average velocity or minimum following distance when driving performance was compared with a control group that did not have either system available. Nor did having had the SSGCS on have an effect on those variables when it was later disengaged. Other variables did show an effect of using the automated systems. This report will be of interest to engineers and researchers involved in Intelligent Transportation Systems and other advanced highway systems.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.

A. George Ostensen, Director
Office of Safety and Traffic Operations
Research and Development

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16. Abstract
The effect on driving performance of using a *speed, steering, and gap control* system (SSGCS) and a *collision warning* system (CWS) was assessed in an experiment conducted in the Iowa Driving Simulator. Driving performance data were obtained from 52 drivers—32 of whom drove with both systems, and 20 controls who did not have access to either.
Results: (1) Driving while using the SSGCS. When the driver was using the SSGCS, there was no effect on speed; however, the driver's car tended to follow further behind the vehicle ahead than did the control-group drivers.
(2) Driving while using only the CWS. With the CWS engaged, drivers controlled both the speed and the steering more precisely than the control-group drivers. This may have occurred the driver was paying more attention than normal to the driving task. When using the CWS alone, the driver's speed was greater than that of the control drivers—particularly in the 100-m (328-ft) fog. This may have occurred because the driver was testing the CWS. Use of the CWS alone had no effect on the following-distance measures.
(3) Driving when the SSGCS and CWS were disengaged. When the driving performance of the experimental-group drivers—with both intelligent systems disengaged after the SSGCS had been activated at least once—was compared with that of the control-group drivers on steering instability, average velocity, and average actual gap, the results were mixed. There was no difference in minimum following distance between the experimental- and control-group drivers. The experimental-group drivers had more steering oscillations, making steering correction movements more frequently than the controls, but without changing their steering instability. They also reduced their velocity instability while increasing the number of velocity fluctuations, they were controlling speed more precisely than the controls, making more frequent corrections of smaller amplitude than the controls. These changes in driving performance may have occurred because the driver had to decide whether, and when, to use the SSGCS and CWS, and may have been paying much more attention than normal to the task of driving.

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Automated highway system, human performance, driving simulation, traffic flow, automation, automated speed, steering, and gap control system, collision warning system, fog, intelligent vehicles, human factors.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Figure | Page

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

Table | Page

SECTION 1. INTRODUCTION

INTRODUCTION

Currently, a great deal of attention is being focused on the possibility of using advanced technologies to develop an Automated Highway System (AHS) that allows hands-off/feet-off travel in one's own vehicle. Human factors issues related to potential implementations of an AHS have been explored in a two-stage program conducted for the Federal Highway Administration (FHWA). In the first stage of the program, seven experiments were conducted in the Iowa Driving Simulator. In the second stage, seven additional experiments have been conducted. This report presents the results of the sixth stage II experiment.

All of the stage I experiments and the first five experiments in stage II used an AHS configuration that would require little structural alteration to the roadways.[1] In contrast, in this experiment an AHS configuration was not used; instead, two intelligent vehicle systems were installed in the driver's car. The first of these, a *speed, steering, and gap control* system (SSGCS), was essentially a cruise-control system that had a selectable following-distance override and was able to steer within a lane; the second was a *collision warning* system (CWS) that was capable of detecting potential collisions and of providing a haptic alert to warn the driver. The experiment was conducted to determine how driving behavior was affected by driving with the aid of these two systems under different visibility and traffic-density conditions.

Fifty-two drivers participated in the experiment; each drove the simulator vehicle for a single trial that lasted 35 min. Thirty-two drivers were assigned to experimental groups: they had access to the intelligent vehicle systems while they were driving. The remaining 20 drivers were controls: the intelligent systems were not installed in the simulator vehicle when they drove.

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[1]This AHS configuration, which consisted of a three-lane expressway in which the left-most lane was reserved for automated traffic that traveled in strings of up to four vehicles, while the vehicles that remained under the control of their drivers traveled in the center and right lanes, was used to investigate the following:

- The transfer of control from the AHS to the driver as the simulator vehicle left the automated lane.(1)
- The transfer of control from the driver to the AHS as the simulator vehicle entered the automated lane.(2,3)
- The acceptability to a driver traveling under automated control of decreasing vehicle separations as a vehicle entered the automated lane ahead of the driver.(4)
- The effectiveness of the driver when he/she was required to control the steering and/or speed when traveling through a segment of the expressway in which the capability of the AHS was reduced.(5)
- The effect on normal driving behavior of traveling under automated control for very brief periods of time.(6)
- The behavior of the driver and the kind of information that he/she wanted to have available when his/her vehicle was traveling under automated control.(7)
- The effect on normal driving behavior of traveling under automated control for an extended period of time (a) when there were different distances between the driver's vehicle and the vehicle ahead and (b) with different methods of transferring control from the automated system to the driver.(8)

During the 35-min trial, driving-performance data were obtained from all 52 drivers while they experienced 1 of 2 traffic densities in 3 different visibility levels. At the start of the trial, the driver's car was positioned on the entry ramp of an expressway. The driver's task was to enter the expressway and drive for the duration of the trial. The drivers in the experimental group were encouraged to use each of the intelligent systems once, but received no further instructions during the drive. The behavior of the drivers was videotaped.

The experiment was conducted with two traffic densities and three visibility conditions. The density was varied between drivers. For half of the drivers (16 from the experimental group and 10 from the control group), the traffic density was 6.41 v/km/ln (10 v/mi/ln), while for the remaining half (also 16 experimentals and 10 controls), the density was 12.42 v/km/ln (20 v/mi/ln). Visibility was a within-subjects variable. The trial was divided into three sections, each of which lasted approximately 11 min. In the first section of the trial, the visibility was clear (10 km [6.21 mi]). At the end of the first section of the drive, radiation fog[2] began to form, reducing the visibility. By the start of the second section, the visibility had dropped to 200 m (656 ft). At the end of the second section of the trial, the fog thickened and the visibility deteriorated again. The driver finished the trial by driving the third section in 100-m (328-ft) fog. The transitions from one level of visibility to the next occurred gradually and naturally. All 52 drivers experienced the three different visibility conditions in the same order. In a previous study, Harms used the Swedish Driving Simulator to investigate the effect of fog on driving behavior.(9) She examined the effect of reduced visibility on the driver's speed and steering performance, and found that the driver's mean speed decreased as the visibility level decreased, but that lateral position and lateral variation were not affected.(9) One of the questions in the current study was whether a similar result would be obtained when the driver was able to use a SSGCS and CWS.

Both objective driving-performance data and subjective driver-preference data were collected during the experimental sessions. Then, the data obtained from the drivers in the experimental and control groups were analyzed and compared in order to determine whether the driving behavior of the drivers who were able to use the intelligent vehicle systems was different from that of those who did not have access to the systems.

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[2]Radiation fog is ground surface-based fog that occurs when ambient air cools to saturation.

OBJECTIVES

The objectives of this experiment were:

- To determine whether driving behavior is affected when the driver has access to a SSGCS and to a CWS.
- To determine whether driving performance is affected by reductions in visibility.
- To determine whether driving performance is affected by variations in traffic density.

To achieve these objectives, driving-performance data were obtained from 52 drivers: 32 drove with both the SSGCS and CWS and 20 were controls. The analyses of these data focused on the following experimental questions:

- *Does driving performance change with the use of the intelligent vehicle systems?*

- *Is driving performance affected by the age of the driver?*

- *Does driving performance change when the visibility level is reduced?*

- *Does driving performance vary with traffic density?*

SECTION 2: METHOD

SUBJECTS

The following guidelines were used to select the drivers who participated in this experiment:

- The drivers had no licensing restrictions, other than wearing eyeglasses for vision correction during driving.
- The drivers did not require special driving devices (the simulator is not equipped for such devices).
- There were 26 younger drivers who were between the ages of 25 and 34.
- There were 26 older who drivers were at least 65 years old, with 13 between the ages of 65 and 69, and 13 who were age 70 or older.
- To ensure that the selected sample accurately represented both genders, half of the drivers in both the younger and older age groups were male, and half were female.
- To increase the probability that the drivers would use the SSGCS and the CWS, all the drivers selected for this experiment responded positively to the following prescreening statement:

  > "In one experiment, we will investigate a car that has two advanced technology systems. One system will be able to maintain a speed that you select, to maintain a following distance that you select, and it will be able to steer automatically. The other is a collision-warning system. Would you be pleased if this advanced technology was installed in your current car, and would you use it?"

The 52 drivers who participated in this experiment were volunteers, recruited through the Iowa City and University of Iowa daily newspapers, who met the above selection criteria.

THE IOWA DRIVING SIMULATOR

The Iowa Driving Simulator, located in the Center for Computer-Aided Design at the University of Iowa, Iowa City, is shown in figure 1.[10] The physical configuration consists of a domed enclosure mounted on a hexapod motion platform. The hexapod motion system employs 1.5-m- (60-in-) stroke hydraulic actuators to induce six-degree-of-freedom motion cues to the driver. The motion system is capable of inducing correlated motion up to 5 Hz, vibration noise up to 8 Hz, and accelerations exceeding 1.0 *g*.

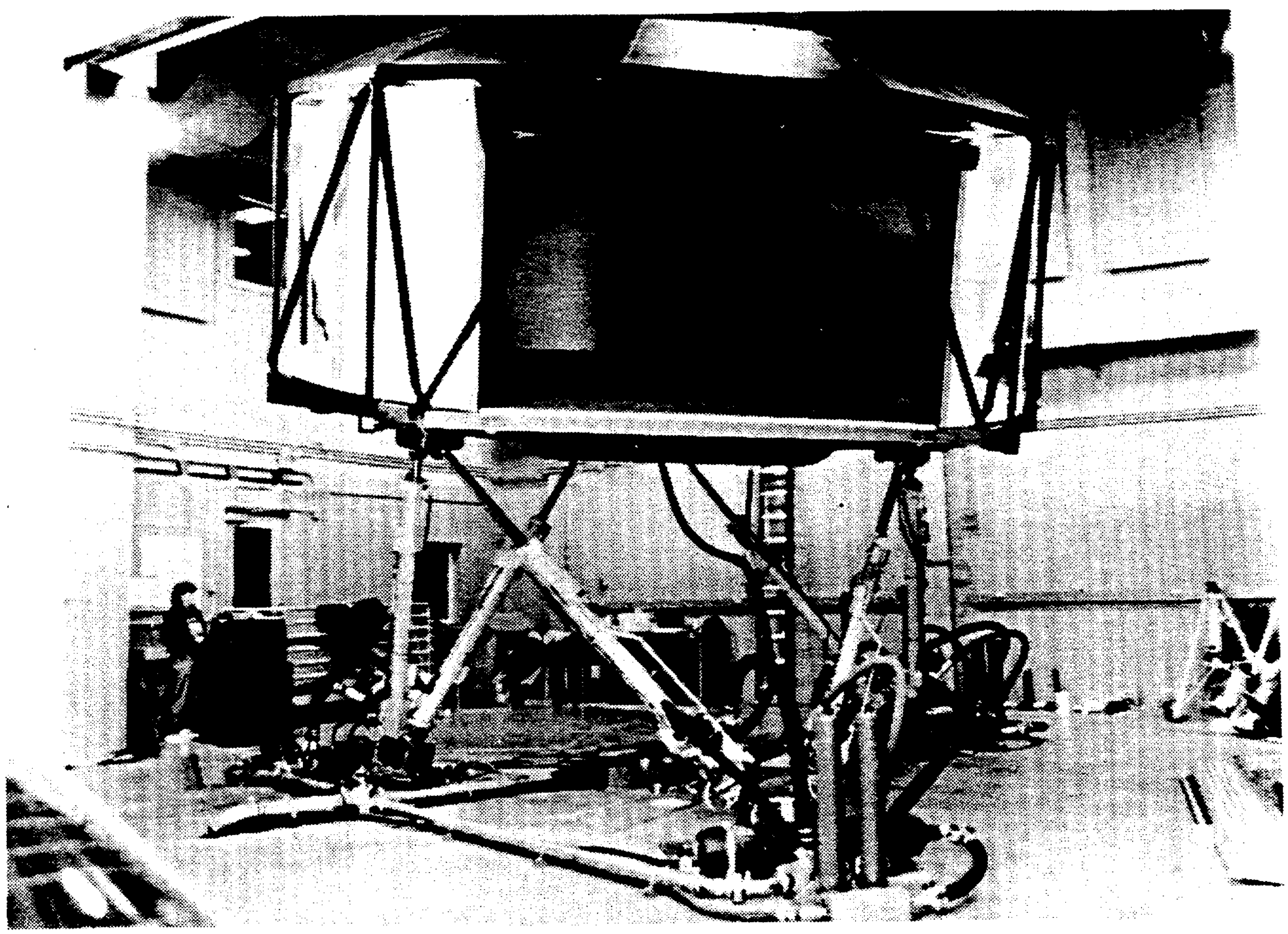

Figure 1. The Iowa Driving Simulator.

In this experiment, a Ford Taurus sedan was mounted on the motion platform and the simulator was controlled by a computer complex that included a Harris Nighthawk 5800 and an Evans and Sutherland ESIG 2000 Computer Image Generator (CIG). The Nighthawk was controlled by the ICON operating system.(11) The Nighthawk was responsible for arbitrating subsystem scheduling and performing motion control, data-collection operations, instrumentation, control loading, and audio cue control. The Nighthawk also performed the multibody vehicle dynamics and complex scenario control simulation.

The inner walls of the dome act as a screen. For the current experiment, the correlated images generated by the CIG were projected onto two sections of these walls—one a 3.32-rad (190°) section in front of the simulator vehicle, the other a 1.13-rad (65°) section to its rear. The driver of the simulator vehicle viewed the images shown on the forward section through the windshield and side windows, and the images projected to the rear either by turning around, through an interior rear-view mirror, or through a left-side exterior driving mirror.

THE INTELLIGENT VEHICLE SYSTEM

The simulator vehicle was equipped with a removable intelligent vehicle system that consisted of two subsystems: the first was a SSGCS; the second was a CWS. The removable system was installed in the simulator vehicle for the trials that were driven by the experimental-group drivers. These drivers had access to this system at all times during the trial. They chose how often to use it, and whether they should use both the SSGCS and the CWS or only one of the two subsystems. In contrast, the removable system was not installed in the simulator vehicle for the trials that were driven by the control-group drivers. These drivers were simply asked to drive throughout the trial.

The driver used the SSGCS to select a speed and a gap. Once they were selected, the SSGCS took control of the steering, keeping the vehicle in the lane, and controlled the speed of the simulator vehicle while preventing it from getting too close to the vehicle ahead.

The CWS was simpler. Once activated by the driver, it issued a warning if the driver's vehicle approached the vehicle ahead so rapidly that a collision was imminent. The warning signal was presented to the driver as an upward force applied to the accelerator pedal (and experienced by the driver as the pedal pushing against his/her foot).

Since in this experiment the minimum gap setting possible with the SSGCS was 0.5 s and the upper speed of the driver's car and the other vehicles on the expressway was unlikely to exceed 112.7 km/h (70 mi/h), if both the SSGCS and the CWS were on at the same time, the driver's car could not approach the vehicle ahead rapidly enough to induce the CWS to issue a warning alert. However, if only the CWS was activated and if the driver was accelerating too rapidly toward the vehicle ahead, then the warning would be given.

The Speed, Steering, And Gap Control System

The control panel that was used to activate both systems was installed in the simulator vehicle to the right of the steering wheel and slightly below the center of the steering wheel. An illustration of the panel is shown in figure 2 without dimensions and in figure 3 with dimensions. Neither figure is to scale.

In this experiment, the driver could not operate the SSGCS until the simulator vehicle had left the expressway entry ramp. However, as soon as the vehicle entered the expressway, the SSGCS could be used, and the light to the left of the *Systems-on/off* indicator—the *off*-light—was illuminated, informing the driver that the system was off. When ready, the driver could activate the SSGCS. He/she did this by pressing the *Set* key. When the *Set* key was pressed, the following things occurred:

- The *off*-light was extinguished.
- The *on*-light was illuminated, informing the driver that the SSGCS had been activated.
- A text message, also informing the driver that the SSGCS had been activated, was presented visually on the left of the message display above the SSGCS and CWS controls.
- The SSGCS took control of the speed of the vehicle.
- The speed at which the SSGCS had been set was presented visually, in miles per hour, to the center-right of the message display.
- The SSGCS took control of the steering, keeping the vehicle in its lane.
- The default gap setting at which the SSGCS had been set was presented visually to the far-right of the message display.

When the SSGCS was first switched on, it was automatically set to the speed at which the vehicle was then traveling. However, the driver could change this speed setting using the *Speed* rocker switch. To increase the speed setting, the driver pressed the upper portion of the switch,

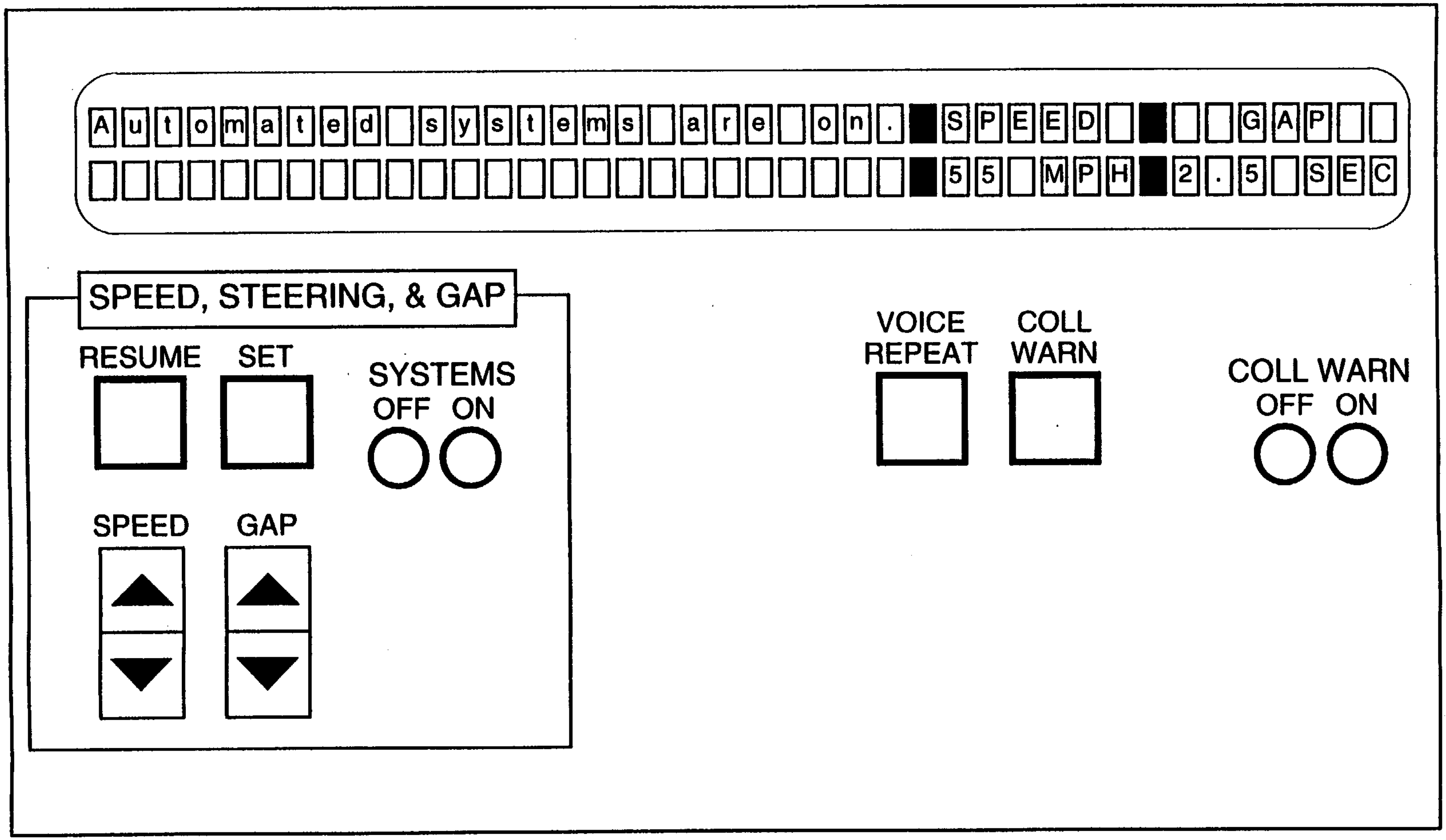

Figure 2. Layout of the control box used in the experiment. [RESUME, SET, VOICE REPEAT, and COLL WARN are pushbuttons; SPEED and GAP are three-position (spring loaded, return to center) rocker switches; SYSTEMS OFF/ON and COLL WARN OFF/ON are indicator lights. The display at the top of the box is a vacuum fluorescent display, with each character formed in a 5-wide by 7-high matrix; upper-case characters are approximately 5 mm (0.2 in) high.]

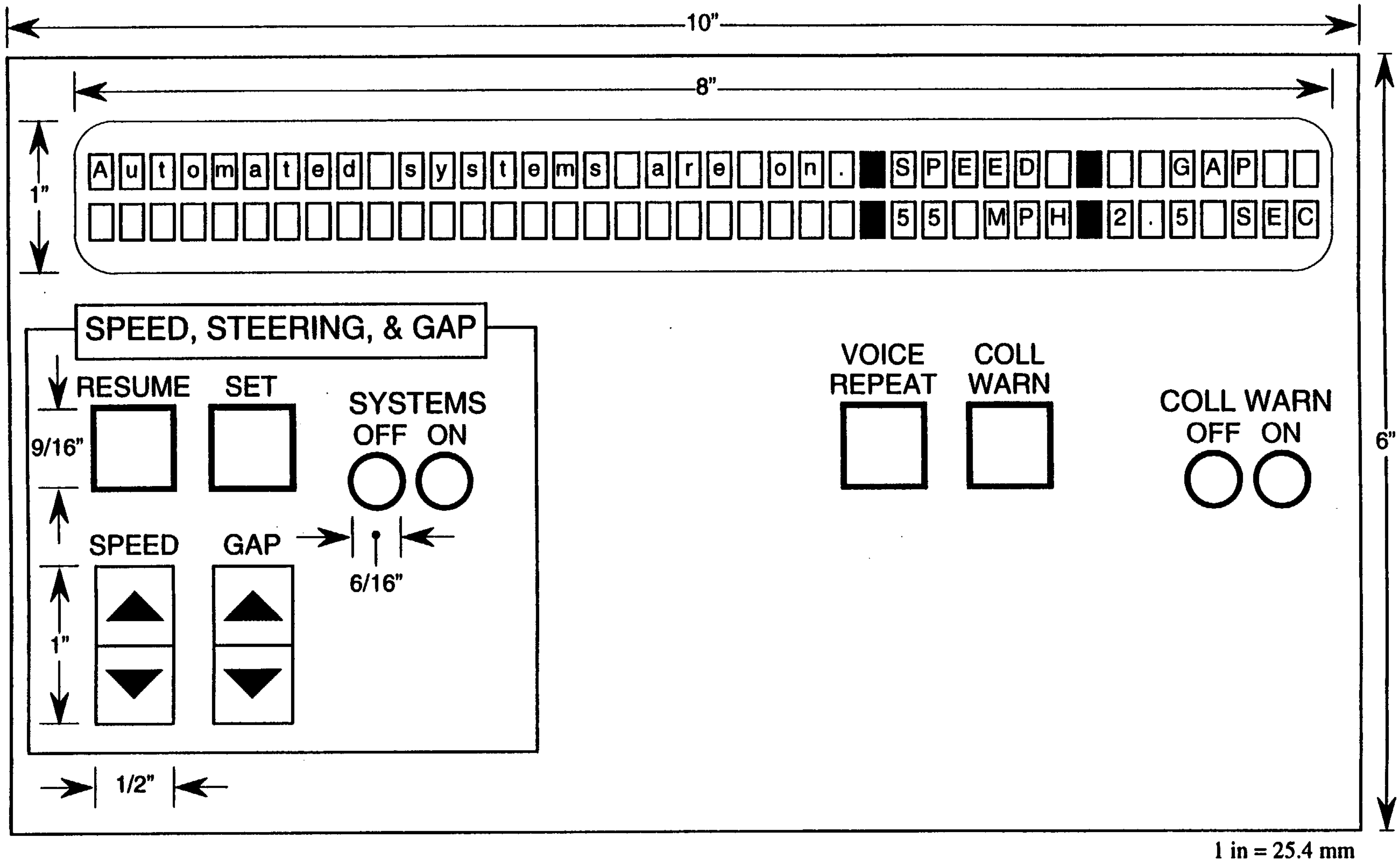

Figure 3. Layout and dimensions of the control box used in the experiment. [Distances between elements (controls and displays) are not to scale; elements for which dimensions are shown are not drawn to those dimensions.]

on which there was an upward-pointing arrow. Every time the driver pressed the upper portion of the switch, the speed setting increased in 1-mi/h increments. The maximum speed to which the driver could set the SSGCS was 99 mi/h. To decrease the speed setting, the driver pressed the lower portion of the *Speed* rocker switch, on which there was a downward-pointing arrow. Each time the driver pressed the lower portion of the switch, the speed setting decreased by 1 mi/h. The minimum speed to which the driver could set the SSGCS was 30 mi/h. The selected speed setting was indicated to the center-right of the message display.

The gap was also automatically set when the SSGCS was first activated. It was set at the current distance between the driver's car and the vehicle ahead, unless that distance was larger than the maximum or smaller than the minimum gap settings that were allowed. If the distance between the driver's car and the vehicle ahead was greater than the maximum allowed gap of 5.0 s, then the SSGCS set the gap, by default, at 5.0 s. Similarly, if the vehicle ahead was closer than the minimum gap of 0.5 s, the SSGCS set the gap, by default, at 0.5 s.

The driver was able to change the gap setting using the *Gap* rocker switch. To decrease the gap setting, the driver pressed the upper portion of the switch, on which there was an upward-pointing arrow. Each time the driver pressed the upper portion of the switch, the gap setting increased in 0.1-s increments. To decrease the gap setting, the driver pressed the lower portion of the *Gap* rocker switch, on which there was a downward-pointing arrow. Every time the driver pressed this lower portion, the gap setting decreased by 0.1 s. The driver could select any gap between the 5.0 s maximum and the 0.5 s minimum. The selected gap setting was presented to the far right of the message display.

The SSGCS used the driver's speed setting as the primary input. The gap setting was the secondary input. The SSGCS controlled the speed of the car and attempted to achieve and maintain the speed selected by the driver. Only if the driver's car got too close to the vehicle ahead would the gap setting input override the speed input.

When both the speed and gap were set, if the driver's vehicle was traveling slower than the set speed, the SSGCS increased the speed until the set speed was matched; if the vehicle was traveling faster than the set speed, the SSGCS decreased its speed. Then, the set speed was maintained by the SSGCS. As long as the distance between the driver's car and the vehicle ahead was longer than the selected gap, the SSGCS continued to maintain or accelerate toward the set speed. However, if while the SSGCS was maintaining or accelerating toward the set speed, the distance between the driver's car and the vehicle ahead decreased until it equaled the gap selected by the driver, then the SSGCS overrode the speed-control input and adjusted the speed of the driver's car to prevent the distance between the two vehicles from decreasing further. The SSGCS then maintained the selected gap, as long as the vehicle ahead traveled at a slower speed than that set by the driver, and the driver elected not to change lanes.

The SSGCS controlled the speed of the driver's car while preventing it from getting too close to the vehicle ahead and keeping it in its lane. However, if the driver wanted to change lanes or overtake another vehicle, he/she had to regain control of the car from the SSGCS. There were three ways in which the driver could disengage the SSGCS:

- Press the accelerator.
- Press the brake pedal.
- Turn the steering wheel as if to change lanes.

On performing one of these actions, the following things occurred:

- The SSGCS returned control of the vehicle to the driver.
- The *On* light was extinguished.
- The *Off* light was illuminated, informing the driver that the SSGCS had been disengaged.
- The driver heard an audio message stating "You must steer and control your speed." [Note: If the driver pressed the *Voice Repeat* key, which was located to the left in the CWS portion of the control panel, this audio message was repeated.]
- A visual message, stating that the SSGCS was off, was presented on the message display.
- The default gap setting at which the SSGCS had been set was presented visually to the far-right of the message display.

After completing the maneuver, the driver could re-engage the SSGCS in several ways. If the driver wanted to keep the same speed and gap settings, then he/she pressed the *Resume* key and the SSGCS would regain control using the previous settings. On the other hand, if the driver wanted to change the speed and/or gap settings, he/she could press the *Resume* key and then use the *Speed* and *Gap* rocker switches to make the changes; alternatively, the driver could accelerate or decelerate to a new speed and then press the *Set* key.

The Collision Warning System

As with the SSGCS, the driver could not operate the CWS until the simulator vehicle left the expressway entry ramp. Once the vehicle entered the expressway, the CWS could be used, and the light to the left of the *Collision Warning-on/off* indicator—the *Off* light—was illuminated, informing the driver that the CWS was not operating. The driver activated the CWS by pressing the *Collision Warning* key; the *Off* light was extinguished, and the *On* light, located to the right of the *Collision Warning-on/off* indicator, was illuminated.

When the CWS was activated, if the driver's car were to approach the vehicle ahead so rapidly that it was in danger of colliding with it, the system warned the driver that a collision was imminent. The CWS used the instantaneous differential separation and differential velocity between the driver's car and the vehicle ahead to continuously compute time-to-collision. Van der Horst found that time-to-collision values that were shorter than 4.0 s were judged by drivers to be dangerous.(12) Because of this, a 4.0-s time to collision criterion was used in Janssen and Nilsson's study examining various collision avoidance systems.(13) The same criterion was used in the current experiment: If the time to collision dropped below 4.0 s, a warning was given to the driver.

Janssen and Nilsson compared collision avoidance systems that provided warnings in several different ways.(13) In one case, the information given to the driver was provided via a continuously displayed visual indicator; at all times, this indicator showed the distance required for the driver's vehicle to stop. Janssen and Nilsson also used three alerting signals that appeared only if the time-to-collision criterion was exceeded. The signal could be visual (the appearance of a red light on the dashboard), auditory (the sounding of a warning buzzer), or haptic (an abrupt 25-N [5.6-lbf] force that was applied to the accelerator pedal). Janssen and Nilsson found that the haptic alert was the only alert of those they tested that produced a reduction in short headways without producing "counter-productive effects in overall speed, speed irregularity, or driving in the left lane." With the other warning systems, "the potential gain in safety obtained by the reduction in short headways was more or less offset by an increase in other, more risky, behaviors."(13) Following Janssen and Nilsson's finding, the warning alert used in the current experiment was a haptic alert; if the time-to-collision criterion was exceeded, the CWS caused the accelerator pedal to push upward against the driver's foot, indicating that he/she should slow down immediately.

If the driver wished to disengage the CWS, he/she had to press the *Collision Warning* key again. Then, the *On* light on the *Collision Warning-on/off* indicator was extinguished, and the *Off* light was re-illuminated.

DRIVING SITUATION

Road Conditions

Each of the participants in this experiment—whether they were in the experimental or control groups—drove on a three-lane expressway that was 96.6 km (60 mi) long. A map of the route is presented in appendix 1. All the vehicles traveling on the expressway were free agents that operated independently of each other. All three lanes were accessible to the driver and to the other vehicles. The lane widths were the current standard 3.66-m (12-ft) expressway width, and a standard road surface was used.

Visibility

During the trial, the driver experienced three visibility conditions. For the first section of the trial, the visibility was 10 km (6.21 mi), which, for drivers on an expressway, is essentially clear. In the second section, the driver drove in fog—the visibility was 200 m (656 ft). Finally, by the third section of the trial, the fog had thickened and the visibility had dropped to 100 m (328 ft).

There are five different types of fog: precipitation fog, steam fog, upslope fog, advection fog, and radiation fog. Because the last of these, radiation fog—a ground surface-based fog, affecting shallow, low-lying areas that is caused when ambient air cools to saturation—is by far the most common type of inland fog, it was modeled in the current experiment. The two visibility transitions—from 10-km (6.21-mi) to 200-m (656-ft) fog, and then from 200-m (656-ft) fog to 100-m (328-ft) fog—occurred gradually and naturally. For the first 10.17-min section of the trial, the visibility was 10 km (6.21 mi). Then, over a 1.25-min interval, the visibility gradually decreased until the driver was traveling in a 200-m- (656-ft-) visibility fog. This visibility level remained unchanged during the 11.67-min second section of the trial, after which the visibility deteriorated again during a 0.25-min interval. In the final 11.67-min section of the trial, the visibility was 100 m (328 ft).

Each driver who participated in the experiment, whether he/she was in the experimental or the control group, drove the simulator vehicle in a single experimental trial that lasted for 35 min.

The drivers who were in the experimental group could activate either the SSGCS and/or the CWS whenever they wished.

Traffic Speed and Fog

The posted speed limit on the expressway throughout the trial was 88.6 km/h (55 mi/h). In the first section of the trial, while the visibility was essentially clear at 10 km (6.21 mi), the vehicles that the driver encountered on the expressway were programmed to travel at an average velocity of 88.6 km/h (55 mi/h). The traffic density was either 6.21 v/km/ln (10 v/mi/ln) or 12.42 v/km/ln (20 v/mi/ln). With these densities and an average velocity of 88.6 km/h (55 mi/h), the mean headway times for the other traffic were 3.27 s and 6.55 s, respectively. [Note: Mean headway time is the difference in arrival time of two consecutive vehicles at a particular observation point on the highway. It includes both the length of the first vehicle and the gap between it and the following vehicle.] The distribution of the velocities of the vehicles was normal, while a Pearson Type III distribution was used to generate the time headways. The method used to generate vehicles in this experiment is described in detail by Bloomfield et al.(1) The parameters used in the equations defining both the normal distribution of velocities and the Pearson Type III distribution were derived using the procedure described by May and using the data provided by May.(14,15)

The velocity of the other traffic decreased, with the visibility, in the second and third sections of the trial. The reductions in velocity were modeled using data, reported by Hawkins (1988), that were obtained by observing traffic traveling in fog on several British expressways.(16) Hawkins showed that, for visibilities greater than 360 m (1180 ft), the mean velocity of expressway traffic did not vary with the visibility.(16) However, when the visibility is less than 360 m (1180 ft), the mean velocity of expressway traffic drops as the visibility decreases. Using Hawkins' data, the proportionate decreases, relative to the mean velocity when the visibility was greater than 360 m (1180 ft), were determined for three visibility levels: 200 m (656 ft), 150 m (492 ft), and 100 m (328 ft). [The intermediate visibility level of 150 m (492 ft) was used to model the gradual decrease in velocity that occurs as the visibility level decreases from 200 m (656 ft) to 100 m (328 ft).] Next, starting with the 88.6-km/h (55-mi/h) average velocity at which the other vehicles traveled in this experiment when the visibility was clear, the proportionate decreases were used to calculate the average velocities for the 200-m (656-ft), 150-m (492-ft), and 100-m (328-ft) visibility levels. These velocities, along with the proportionate decreases, are shown in table 1.

Table 1. Average proportionate velocity and average resultant velocity for vehicles in three visibility levels.[1]

Visibility	Percentage of Velocity When Visibility was Greater Than 360 m (1180 ft)[a]	Velocity[b]
200 m (656 ft)	93.7	82.97 km/h (51.53 mi/h)
150 m (492 ft)	88.2	78.10 km/h (48.51 mi/h)
100 m (328 ft)	77.2	68.36 km/h (42.46 mi/h)

[a] For example, when the visibility was 200 m (656 ft), the expressway average velocity fell to 93.7 percent of that when the visibility was 360 m (1180 ft). The proportionate velocities shown here were determined using Hawkins' graph of the relationship between visibility level and observed traffic speed—see Hawkins (figure 4, page 14).(16)

[b] This velocity is 88.6 km/h (55 mi/h) multiplied by the percentage in the adjacent cell to the left.

The velocities shown in table 1 were used, in conjunction with the traffic generation method described by Bloomfield et al., to generate the range of velocities of the other traffic encountered by the driver in the reduced visibility sections of the trial.(1) When the average speed dropped to 82.97 km/h (51.53 mi/h) in the 200-m (656-ft) fog, the mean headway times for the traffic in the 6.21-v/km/ln (10-v/mi/ln) and 12.42-v/km/ln (20-v/mi/ln) traffic densities were 6.99 s and 3.49 s, respectively; for the 100-m (328-ft) fog, where the average speed was 68.36 km/h (42.46 mi/h), the mean headway times for the two traffic densities were 8.48 s and 4.24 s, respectively.

EXPERIMENTAL DESIGN

In the current experiment, there were four independent variables. The first, the level of visibility, was a within-subjects variable that was held constant among subjects. The second, the age of the driver, was a between-subjects variable that could have affected driving performance. The third variable was a between-subjects variable that examined the effect of traffic density on the driving-performance data collected throughout the trial. Finally, the fourth variable, availability of the SSGCS and CWS, was also a between-subjects variable.

Level of Visibility

The level of visibility was a within-subjects variable. All drivers experienced a 35-min drive. For the first section of the trial, lasting 10.17 min, the visibility was 10 km (6.21 mi) (i.e., it was essentially clear). The second section of the trial was 11.67-min long; in it, the visibility was 200 m (656 ft). In the third and final section of the trial, which also lasted 11.67 min, the visibility was 100 m (328 ft).

To preserve the natural experience of driving, the levels of visibility were not randomized—the order of presentation was the same for all the drivers. It should be noted that, if there are improvements in driving performance, due to practice, that occur throughout the trial, they would tend to obscure any detriment in performance that might occur because of the deterioration in visibility. However, if driving performance is found to be significantly worse when the visibility is poorer, in spite of the possible improvements from practice, the result can be relied upon.

Age of the Driver

The 52 drivers who took part in the current experiment were balanced between two age groups. The first group consisted of drivers between 25 and 34 years old; the drivers in the second group were 65 and older. There were 26 drivers in each group. Of the 26 younger drivers, half were male and half were female. Within the group of older drivers, there was a further subdivision: 13 drivers were between 65 and 69 years old and 13 were 70 or more. This was done to ensure that the participants would not cluster just above 65 years at the lower end of the age group, but would instead cover a relatively wide range. Of the 13 subjects between ages 65 and 69, 7 were male and 6 were female. Of the 13 who were age 70 or older, 6 were male and 7 were female.

Traffic Density

Traffic density was a between-subjects variable. The drivers drove throughout the trial with one of the following two traffic densities:

- The lower traffic density was 6.21 v/km/ln (10 v/mi/ln). This is a level close to the upper boundary of the Transportation Research Board Level of Service A (LOS A).[17] At this density level, traffic flows freely.
- The higher density was 12.42 v/km/ln (20 v/mi/ln). This density level is at the upper boundary of LOS B. When the traffic is this dense, the traffic flow is stable, but the

presence of the other vehicles is noticeable and there is a slight decline in the freedom to maneuver.

Half of the drivers in the younger and older groups drove among lower density traffic, while the other half of the drivers in both age groups drove among higher density traffic.

Availability of the SSGCS and the CWS

Twenty of the 52 drivers, 10 each from the younger and older age groups, participated as the control group. The remaining 32 drivers, 16 from the younger age group and 16 from the older group, drove with an intelligent vehicle system that included a SSGCS and CWS that were described in detail earlier in the "Intelligent Vehicle System" subsection of this report.

Assignment of Drivers to Experimental Conditions

All 52 drivers experienced the same three visibility levels in the same order. However, because the other three independent variables were all between-subjects variables, it was necessary to assign the drivers to one of eight groups so that comparisons could be made between the different combinations of conditions. The drivers were randomly assigned to these groups in the way shown in table 2.

Table 2. Number of drivers in each combination of traffic density, age of the driver, and system exposure.

	Experimental Group		Control Group	
Traffic Density	Younger Drivers	Older Drivers	Younger Drivers	Older Drivers
6.21 v/km/ln (10 v/mi/ln)	8	8	5	5
12.42 v/km/ln (20 v/mi/ln)	8	8	5	5

As the table shows, the 32 drivers in the experimental group, who were able to use the SSGCS and CWS while they were driving on the expressway, were divided into 4 subgroups of 8 each.

There was a subgroup for each combination of driver's age and traffic density. Similarly, the 20 control group drivers were divided into 4 subgroups of 5 drivers each, and again each subgroup was assigned to one of the 4 combinations of driver's age and traffic density. The detailed assignment of the 52 drivers to the combinations of the conditions tested in the experiment is presented in appendix 2.

EXPERIMENTAL PROCEDURE

Experiment six was divided into two parts. In the first part, the drivers watched an introductory videotape, drove for one experimental trial in the Iowa Driving Simulator, and filled out a questionnaire. In the second part of the experiment, the driver's visual capabilities were assessed.

Introduction, Training, and Practice Procedure

Before the start of the experiment, each driver watched a videotape containing introductory material describing this research program, the SSGCS and the CWS, and providing some interactive practice with the SSGCS and CWS control panels. The driver was told that the experiment involved driving in the simulator and completing a vision test and a questionnaire. He/she was informed that the experiment was part of an FHWA program focused on determining whether newly developed technology will help to reduce congestion and increase highway safety. The program would also determine how this advanced automobile technology should be designed and how it should be used. It was made clear that the experiment was a test of the technology, not a test of the driver, and that his/her privacy would be maintained. The video then provided details to the driver on how to:

- Activate the SSGCS.
- Set the desired velocity and gap.
- Disengage the SSGCS.
- Re-engage the SSGCS.
- Activate the CWS.
- Disengage the CWS.
- Respond to the haptic alert given by the CWS.

Two different training videos were prepared. The first video was prepared for the drivers who could use the SSGCS and CWS. It lasted 7 min. The second video was for the control group drivers, who did not have the SSGCS and CWS installed when they drove. The second video required far less detail than first and was only 2 min in length. The narratives for both versions of the training videos are presented in appendix 3.

The soundtrack to both videos was played to all 52 drivers at a volume that was pre-set to match the volume that would be heard in the simulator vehicle. Prior to hearing the training video, the participants were asked to pay particular attention to any audio messages, as they would be exactly what would be heard in the vehicle. Then, after the training video was complete, the participant was asked:

> "Did you have any difficulty hearing any of those messages?"

This procedure was adopted to ensure that each driver would be able to hear the messages when they were presented during the experimental trial.

After the instructional section of the videos, the 32 drivers in the experimental group had an opportunity to practice using the SSGCS and the CWS by means of a mockup version of the systems that had been installed on a laptop computer. The experimenter provided instructions to each driver in the experimental group in order to ensure that the use of the computer was thoroughly understood. To imitate the actions he/she would take in the simulator, the driver clicked on the appropriate box on the computer screen, using the mouse. The training instructions and an illustration of the mockup device appear in appendix 4.

After the experimenter finished presenting the training instructions, the driver was allowed to practice freely with the computer. The driver could ask questions at any time.

Pre-Experimental Simulator Procedure

Next, the driver was taken to the Iowa Driving Simulator and seated in the driver's seat of the simulator vehicle. The driver was asked to put on the seat belt and adjust the seat and mirrors, and then was given instructions on how to use the simulator emergency button. The driver was informed that the headlights of the simulator vehicle were already switched on, and that the air conditioner, dome lights, turn signal, and radio were operational. The driver was told that if for any reason he/she wanted to stop at any time during the drive, he/she should tell the experimenter. On hearing this request on the intercom, the simulator operator would stop the simulation.

Experimental Procedure and Instructions

Each participant drove the simulator vehicle for one extended trial that lasted approximately 35 min. At the beginning of the trial, the vehicle was parked on a freeway entrance ramp. The driver was reminded that he/she would be driving on a freeway with three lanes in each direction, and would be free to drive in any lane. The driver was told that the speed limit was 55 mi/h and the recommended minimum gap was 2.0 s.

A review of the SSGCS and CWS was conducted for the drivers in the experimental group; these drivers were told that they were free to use the SSGCS and/or the CWS at any time. The driver was instructed to drive into the right lane of traffic on the three-lane expressway, and drive for the duration of the trial. The drivers in the experimental group were invited to use the SSGCS and CWS as much as they pleased.

When a driver from the experimental group pressed the *Set* key to activate the SSGCS, the system took control of the speed and steering, the *Off* light on the *Systems-on/off* indicator was extinguished, the *On* light was illuminated, and the selected speed and gap were reported on the message display. The driver was informed that he/she would not be able to engage the SSGCS if, at the same time the *Set* key was pressed, he/she was pressing the accelerator or brake pedal or turning the steering wheel, because these were the actions that were to be used to disengage the system.

The driver knew that, once activated, the SSGCS would keep the vehicle in its lane. In addition, the driver knew that the system would maintain the selected speed (or accelerate or decelerate to it), and that the SSGCS would continue to maintain the speed unless the driver's car got so close to the vehicle ahead that it was within the set gap. If this were to occur, the SSGCS would override the speed control.

The SSGCS could be activated or deactivated by the driver at any time. The driver was informed that, if the CWS was activated at the same time as the SSGCS, the gap setting of the latter would prevent his/her car from approaching the car ahead too fast so that, in these circumstances, the CWS would not issue a haptic alert. However, if a vehicle moved from another lane into the driver's lane in front of, and close enough to the driver's car so that a collision might occur, then the CWS would issue an alert.

After the driver had driven for 35 min and experienced the three levels of fog, he/she was asked to pull over to the side of the road and stop.

Each driver in the control group drove on the same expressway for the same length of time and experienced the same three visibility levels as the drivers in the experimental group. In addition, each control-group driver was informed that the speed limit was 55m/h and that the recommended minimum gap was 2.0 s. The driver was also told that he/she was free to drive in any lane.

Post-Experimental Procedure

After completing the trial, the drivers in both the experimental and control groups returned to the subject preparation room. Once there, each driver was debriefed and asked to complete a questionnaire that contained questions dealing with the driving simulator, his/her drive in the simulator vehicle, and—if the driver had been in the experimental group—the functionality of the SSGCS and the CWS. There was a separate version of the questionnaire for the drivers who were in the control group. Copies of these questionnaires are presented in appendix 5.

At this point the first part of the experiment ended.

Most of the drivers who participated in the experiment took a 5-min break before the second part of the experiment began. A few drivers were unable to complete the visual testing on the same day; they returned on a later date.

In the second part of the experiment, the visual capabilities of the driver were assessed. This was done simply to see whether any subject had an anomaly that would warrant taking a closer look at his/her data. The vision testing was divided into two sections. In the first section, a standard set of vision tests was administered: far foveal acuity, near foveal acuity, stereo depth perception, color deficiencies, lateral misalignment, and vertical misalignment. In the second section, the spatial localization perimeter developed by Wall was used to determine the subject's reaction time and accuracy when detecting both static and dynamic peripheral stimuli.(18)

SECTION 3. RESULTS

FOCUS OF THE DATA ANALYSIS

The results of the visual testing did not reveal the need to treat any subjects' data differently from the others'.

The objectives of the experiment were to determine whether: (1) driving behavior is affected when the driver has access to a SSGCS and to a CWS, (2) driving performance is affected by reductions in visibility, and (3) driving performance is affected by variations in traffic density. Driving-performance data were obtained from 52 drivers: 32 drove with both the SSGCS and CWS and 20 were controls. The analyses of the data focused on the following experimental questions:

- *Does driving performance change with the use of the SSGCS and CWS?*
- *Is driving performance affected by the age of the driver?*
- *Does driving performance change when the visibility level is reduced?*
- *Does driving performance vary with traffic density?*

To answer these questions, driving performance data were collected from 52 drivers who traveled on a simulated journey of approximately 35 min. The drivers were divided into two groups. The SSGCS and CWS were installed in the simulator vehicle for the 32 drivers in the experimental group, while these two systems were not available to the 20 drivers in the control group.

Driving Performance Measures

The performance measures listed in table 3 were collected from the experimental- and control-group drivers during and after the 35-min journey.

Partitioning the Data

All 52 drivers experienced driving with 3 levels of visibility. At two points in the journey, there was a gradual deterioration in visibility. Before the first of these reductions, the visibility was

Table 3. Performance measures.

Lane-keeping measures	• Steering instability.[1] • Number of steering oscillations.[1]
Speed-control measures	• Average velocity. • Velocity instability.[1] • Number of velocity fluctuations.[1]
Following-distance measures	• Minimum gap setting/following distance • Average gap setting/actual gap
Lane-change measures	• Number of lane changes. • Percentage of time spent in the right lane. • Percentage of time spent in the center lane. • Percentage of time spent in the left lane • Size of gap accepted in a lane change.
Incursion measures	• Number of incursions. • Size of gap rejected in a lane incursion.
SSGCS activation measure	Percent of time SSGCS activated
Impressions about the experiment	Questionnaire responses

[1] Driving-performance measures developed by Bloomfield and Carroll.(19) [A brief account describing the development of these measures is provided in appendix 6.]

clear for 10 km (6.21 mi). The driver traveled on the expressway with this initial visibility for 10.17 min. At the end of the first section of the journey, during a 1.25-min interval, it became foggy and the visibility decreased to 200 m (656 ft). The driver experienced driving with this reduced visibility for 11.67 min. Next, the second drop in visibility occurred. It dropped to 100 m (328 ft), and stayed at this level for the remaining 11.67 min of the journey. Data were collected from all 52 drivers throughout the journey, from the time they entered the expressway until the end of the 35th minute, when a message was issued requesting the driver to pull over onto the shoulder. The data analyzed here were obtained during the three sections of the journey in which the visibility was stable. The data obtained in the two intervals during which there were transitions between visibility levels were omitted from the analysis.

The data obtained from drivers in the control group for each of the measures in table 3, with the exception of the percentage of time the SSGCS was activated and the responses to the questionnaire, were partitioned in terms of the three visibility levels only.

However, the partitioning of the data from the drivers in the experimental group was more complex. For the experimental-group drivers, in addition to the partitioning based on visibility level, the data relating to the two lane-keeping measures, three speed-control measures, and two following-distance measures were also divided in terms of whether the SSGCS and the CWS were activated. The additional categories were as follows:

- Driving-performance data that were obtained while the driver was using the SSGCS.
- Driving-performance data that were obtained while the driver was using the CWS only, i.e., that were obtained when the CWS was activated and the SSGCS was disengaged.
- Driving-performance data that were obtained when both the SSGCS and the CWS were disengaged, but were obtained after the driver had activated the SSGCS at least once. [Note: Data obtained when both the SSGCS and the CWS were disengaged but *before* the driver had activated the SSGCS at least once were not included in the analysis.]

Since lane changes and incursions were not possible with the SSGCS activated, the lane-change and incursion measures (in table 3) were partitioned by visibility level only. The SSGCS usage data were also partitioned by visibility level only, for obvious reasons.

Organization of the Analysis

The analysis is divided into six sections. The first is a brief section that shows the result of a cross-experimental comparison in which the driving performance of the drivers in the control group in the current experiment is compared with the driving performance of drivers in the control group in the previous study in this series by Bloomfield, Levitan, Grant, Brown, and Hankey.[8]

The second analysis section presents the analysis of the percentage of time the experimental group had the SSGCS activated.

The third analysis section examines the driving performance of the experimental-group drivers when they were using the SSGCS. Since this experiment was carried out in order to discover how the driver's performance might be affected by use of the SSGCS, it did not make sense to include in this particular analysis the measures of lane keeping and speed control, both of which were under the control of the SSGCS. Instead, the analysis concentrates on one velocity measure (the average velocity) and two following-distance measures (the minimum gap setting and following distance, and the average gap setting and actual gap).

The fourth analysis section focuses on the driving performance of the experimental-group drivers when they were using the CWS alone. This analysis was conducted using the first seven measures listed in table 3 (i.e., the two lane-keeping measures, the three speed-control measures, and the two following-distance measures).

The fifth analysis section explores the data obtained from drivers in the experimental group when they were not using either the SSGCS or the CWS, after they had used the SSGCS at least once. As in the third section, this analysis was conducted using the first seven measures listed in table 3.

In the sixth analysis section, the result of the analysis of the remaining driving-performance measures, the five lane-change measures and the two incursion measures, are presented. The comparisons that were made were between the data obtained from the control-group drivers and the data from those who were in the experimental group; for the latter group in this analysis, the data collected when only the CWS was activated were combined with data obtained when neither the SSGCS nor the CWS were activated.

In the seventh and final analysis section, the results of the questionnaire that was administered after the participants had driven in the simulator are presented. The questionnaire contained questions dealing with the driving simulator, the journey in the simulator vehicle, and, if the driver had been in the experimental group, the functionality of the SSGCS and the CWS. There was a separate version of the questionnaire for drivers in the control group.

CROSS-EXPERIMENTAL COMPARISON OF THE PERFORMANCE OF CONTROL-GROUP DRIVERS

The performance of the control-group drivers in the current experiment was compared with the performance of the control-group drivers in the previous experiment in the current series. The 12 control-group drivers in that experiment drove in traffic with a density of 12.42 v/km/ln (20 v/mi/ln) when the visibility was clear.[8] Although they traveled on a three-lane expressway, the control-group drivers were only able to drive in the right and center lanes; this was because in that experiment the left lane was reserved for automated traffic. Bloomfield et al. analyzed data obtained from the control-group drivers in a 9.5-min period early in the trial, after a 5-min practice period.[8]

Ten of the 20 control-group drivers in the current experiment also drove in traffic with a density of 12.42 v/km/ln (20 v/mi/ln) when the visibility was clear. Driving-performance data were collected from them during the first 10 min of the journey, while they drove on a three-lane expressway. Unlike the drivers in the earlier study, these drivers had access to all three lanes of the expressway.

The average performance of the 12 control-group drivers in the earlier experiment and the 10 drivers in the current experiment who drove in traffic with a density of 12.42 v/km/ln (20 v/mi/ln) for two lane-keeping measures and three steering-performance measures are shown in table 4. These data are directly compared in figure 4.

Table 4. Comparison of mean driving-performance data for control-group drivers in the current experiment and in the previous experiment by Bloomfield et al.[8]

Driving-Performance Measures	Means for Control-Group Drivers in the Previous Experiment	Means for Control-Group Drivers in the Current Experiment
Steering instability	0.27 m (0.87 ft)	0.31 m (1.01 ft)
Steering oscillations	13.07 per min	14.47 per min
Average velocity	85.9 km/h (53.3 mi/h)	82.8 km/h (51.4 mi/h)
Velocity instability	4.5 km/h (2.8 mi/h)	6.0 km/h (3.7 mi/h)
Velocity fluctuations	3.09 per min	2.68 per min

Figure 4 provides a comparison of the driving-performance data that were obtained from the control-group drivers in the previous experiment by Bloomfield et al. and in the current experiment.[8] The five graphs shown in the figure compare: (a) steering instability, (b) the number of steering oscillations per minute, (c) average velocity, (d) velocity instability, and (e) the number of velocity fluctuations per minute. On all five graphs, the 95-percent confidence interval is shown, along with the mean, for each driving measure. This allows a direct comparison of the performance of the controls in the two experiments to be made. When each of the five graphs is

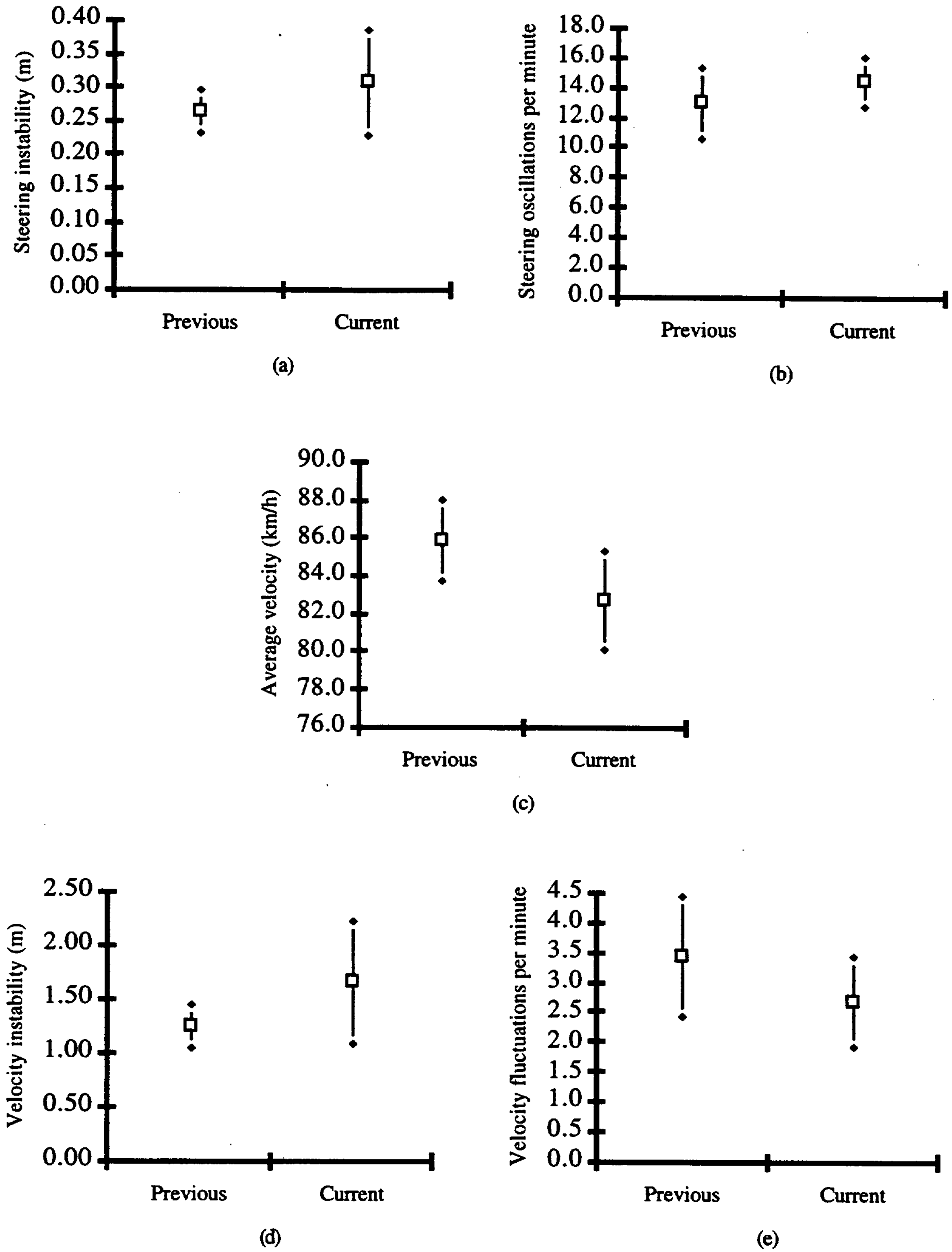

Figure 4. Mean values (with 95% confidence interval) of: (a) steering instability, (b) steering oscillations per min, (c) velocity, (d) velocity instability, and (e) velocity fluctuations per minute for control-group drivers in the current experiment and a previous experiment by Bloomfield et al.[8]

inspected, it can be seen that, in each case, there is a large overlap in the confidence intervals for the two sets of data. This overlap is consistent with the view that the driving performance of the control-group drivers in the previous experiment and in the current experiment was essentially the same.

PERCENTAGE OF TIME THE SSGCS WAS ACTIVATED

During the three visibility periods, each driver in the experimental group had to decide whether, and how much, he/she wanted to drive on the expressway with the SSGCS activated. To determine the percentage of time that the SSGCS was activated, the total amount of time that the SSGCS was activated in each of the three periods was recorded. Then, these totals were converted into percentages.

Table 5 shows the percentage of time that the SSGCS was activated by the older and younger experimental-group drivers for each of the three visibility conditions.

Table 5. Percentage of time the SSGCS was activated as a function of age and visibility level.

Visibility	Age 25–34	Age ≥65
10 km (6.21 mi)	57.2	59.2
200 m (656 ft)	61.0	93.4
100 m (328 ft)	55.9	79.6

As can be seen from the table, visibility level had little effect on SSGCS usage for the younger drivers: they had the system activated about 55 to 60 percent of the time, regardless of visibility level. While the usage by older drivers was similar to that for younger drivers in clear visibility (10 km [6.2 mi]), older drivers apparently activated the system more of the time when the visibility was reduced.

DRIVING WHILE USING THE SSGCS

To determine how the driver's performance was affected when he/she was using the SSGCS, the performance of drivers using the SSGCS was compared with that of drivers in the control group. Only a limited set of comparisons could be made. This was because when it was activated, the

SSGCS itself was responsible for controlling the steering, the speed of the driver's car, and the distance between the driver's car and the vehicle ahead. As a result, the comparisons were not made with several of the measures listed in table 3, including the lane-keeping measures and two of the three speed-control measures. However, there were three measures of driving performance in table 3 that could be used. When they were using the SSGCS, the drivers in the experimental group selected the speed of the simulator car and the gap between it and the vehicle directly ahead, which allows the following comparisons to be made:

- The average velocity of the drivers in the control group was compared with the average velocity of the experimental-group drivers.
- The minimum following distance of the control-group drivers was compared with the minimum gap set by those in the experimental group.
- The average actual gap of the drivers in the control group was compared with both the average actual gap of the drivers in the experimental group and with the average gap set by the latter.

These comparisons were conducted using analyses of variance (ANOVA's), with the results reported below.

Average Velocity While Using the SSGCS

The ANOVA conducted on the average velocity data indicated that two variables were statistically significant, as shown in table 6. The complete summary for this ANOVA is presented as table 43 in appendix 7.

Table 6. Summary showing only the statistically significant effects found by the ANOVA used to determine if average velocity was affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age	0.0001
Visibility	0.0001

As can be seen from the table, only two variables, the age of the driver and the visibility level, had significant effects on the average velocity. There was no evidence to suggest that the variation in the density of the traffic affected the average velocity. There were no significant interactions.

In addition, and most importantly, there was no evidence to show that, while the experimental-group drivers were using the SSGCS, their vehicle traveled at a different speed compared with the average speed of the drivers in the control group (who had no access to the SSGCS).

Age of the Driver. Table 6 indicates that the average velocity was affected by the age of the driver. The effect is illustrated in figure 5.

As the figure shows, the older drivers drove slower than the younger drivers. The average velocity throughout the trial was 73.8 km/h (45.9 mi/h) for the older drivers and 80.2 km/h (49.8 mi/h) for the younger drivers. It should be noted that the data shown on figure 5 are averaged over group—over both the experimental drivers (when the SSGCS was in use) and the control-group drivers—traffic density, and visibility level.

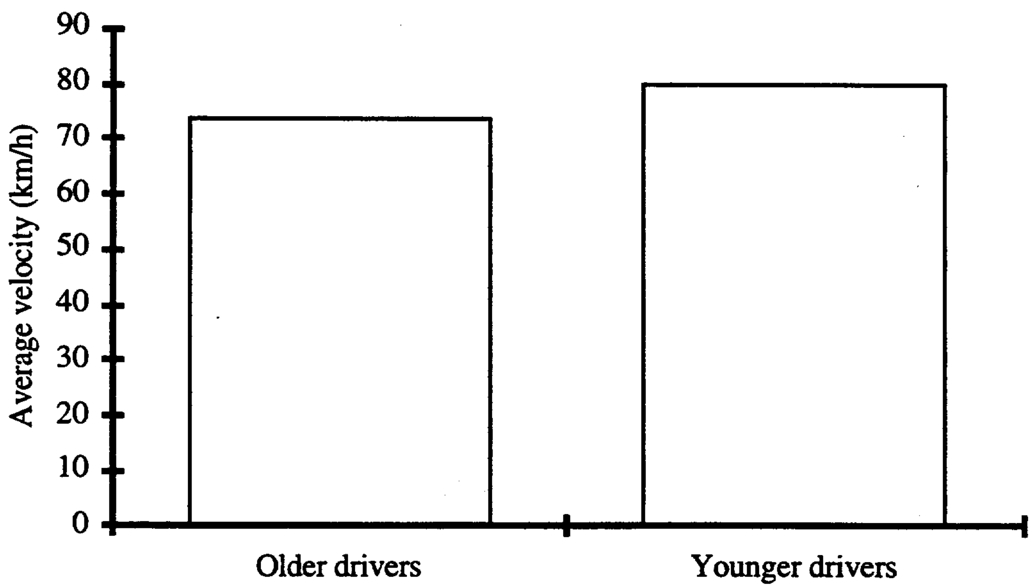

Figure 5. Average velocity for older and younger drivers.

Visibility. Table 6 indicates that the average velocity was affected by visibility. Tukey's Studentized Range test was conducted on the data *post hoc*. It showed that the average velocities when the visibility was clear, when it was 200 m (656 ft), and when it was 100 m (328 ft), were each significantly different from each other. The effect of driving in fog, which first reduced the visibility from 10 km (6.21 m) to 200 m (656 ft) and then to 100 m (328 ft), is illustrated in figure 6.

Figure 6 indicates that the average velocity decreased as the visibility decreased. This result was expected. When visibility was clear, the average velocity was 84.1 km/h (52.3 mi/h). In the second section of the journey, the visibility dropped to 200 m (656 ft) and the velocity dropped to 80.2 km/h (49.8 mi/h). The latter is 95.3 percent of the velocity in the clear condition, which is very similar to the 93.7 percent (calculated from Hawkins' observational data for this visibility) that was used to determine the speed of the other vehicles present on the expressway in this experiment.(16) In the third section of the journey, when the visibility deteriorated still further to 100 m (328 ft), the average velocity dropped again, to 67.3 km/h (41.8 mi/h), which is 77.9 percent of the velocity in the clear condition—again, almost identical to the 77.2 percent calculated from the data reported by Hawkins for this visibility.(16)

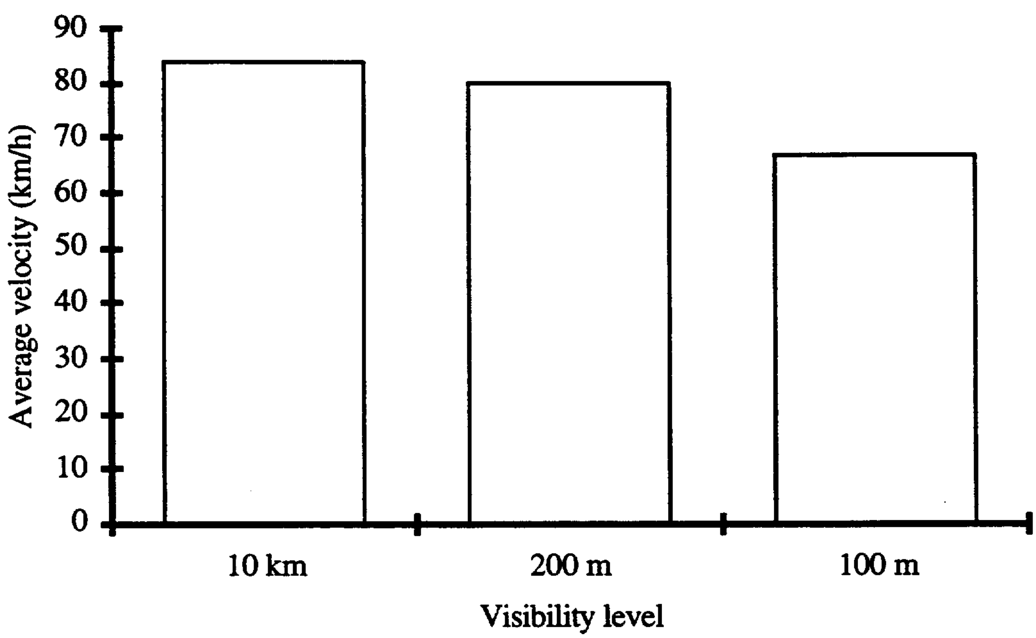

Figure 6. Average velocity as a function of visibility.

Minimum Following Distance and Use of the SSGCS

For drivers in the control group, minimum following distance was derived in the same way as it had been in earlier experiments by Bloomfield, Christiansen, and Carroll(6) and Bloomfield, Levitan, Grant, Brown, and Hankey.(8) That is, it was obtained by continuously calculating the distance between the driver's car and the vehicle ahead, and then applying a set of criteria to the data to determine the minimum following distance that the driver actually selected, rather than a shorter distance that might have been imposed on the driver by another vehicle cutting into the lane.[3]

In contrast, for drivers in the experimental group who were using the SSGCS, the shortest gap setting that these drivers selected was used as the measure of minimum following distance.[4] Because the experimental-group drivers were asked to set the gap in seconds, it seemed appropriate to convert the minimum following-distance measures of the control-group drivers to seconds.[5] Table 7 summarizes the results of the ANOVA conducted to compare the minimum following distance of the drivers in the control group with the minimum gap set by the drivers in the experimental group while they were using the SSGCS. The complete summary for this ANOVA is presented as table 44 in appendix 7.

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[3]To determine the minimum following distance for each control-group driver within each visibility level, the following procedure was used. First, for each of the three visibility levels, the gap between the front bumper of the driver's car and the back bumper of the vehicle ahead was recorded at 30 Hz. Second, if the driver changed lanes, the data obtained during the lane change were eliminated from consideration. Third, whenever the gap between the driver's vehicle and the vehicle ahead exceeded 440 m (1443 ft), the data were eliminated from consideration. Fourth, if after a break in the data the gap increased continuously, the lowest point was ignored (if the gap was continuously increasing, this may have been because the driver was uncomfortable with the gap and had reduced speed to increase it). Fifth, if before a break in the data the gap decreased continuously, the lowest point was also ignored (if the gap was continuously decreasing, this may have been because the gap was still larger than the minimum following distance that was acceptable to the driver). Sixth, the lowest point was selected. Seventh, it was determined whether there were gap data for at least 10 s around the lowest point—if there were less than 10 s of data, they were discarded. Eighth, the gap data acquired in any period that was 10 s or more were examined—if during this 10-s period the gap exceeded the lowest point by 133 percent, the data were discarded (this is because the lowest point may have occurred because another vehicle moved into the lane ahead of the driver, leaving a gap that was smaller than was acceptable to the driver who, as a result, reduced speed to increase the gap). Ninth, in the two restricted-visibility-level conditions, if the gap was longer than the visibility limit—either 200 m (656 ft) or 100 m (328 ft)—then the data were discarded (this is because, for any gap longer than the visibility limit, the driver would not have been able to see the vehicle ahead). Tenth, if the data met all the criteria listed above, the lowest point was reported as the minimum following distance for the driver within each visibility level.

[4]As long as it met the eighth of the minimum following-distance criteria, i.e., that the gap setting was maintained continuously for 10 s or more.

[5]When this measure was used in previous experiments in this series, and, later in this report, when it is analyzed for experimental-group drivers when they were using the CWS alone, and when they were no longer using either the SSGCS or the CWS, the minimum following distance is reported in meters (and feet).(6,8)

Table 7. Summary showing only the statistically significant effects found by the ANOVA used to determine if the minimum following distance (in seconds) was affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age	0.0001
Group by age by visibility level	0.0243

Table 7 indicates that the ANOVA conducted on the minimum following-distance data found two statistically significant effects. The age of the driver affected the minimum following distance. Also, there was a significant three-way interaction among group, driver age, and visibility level.

<u>Interaction of Group, Age, and Visibility.</u> The three-way interaction is explored in figure 7.

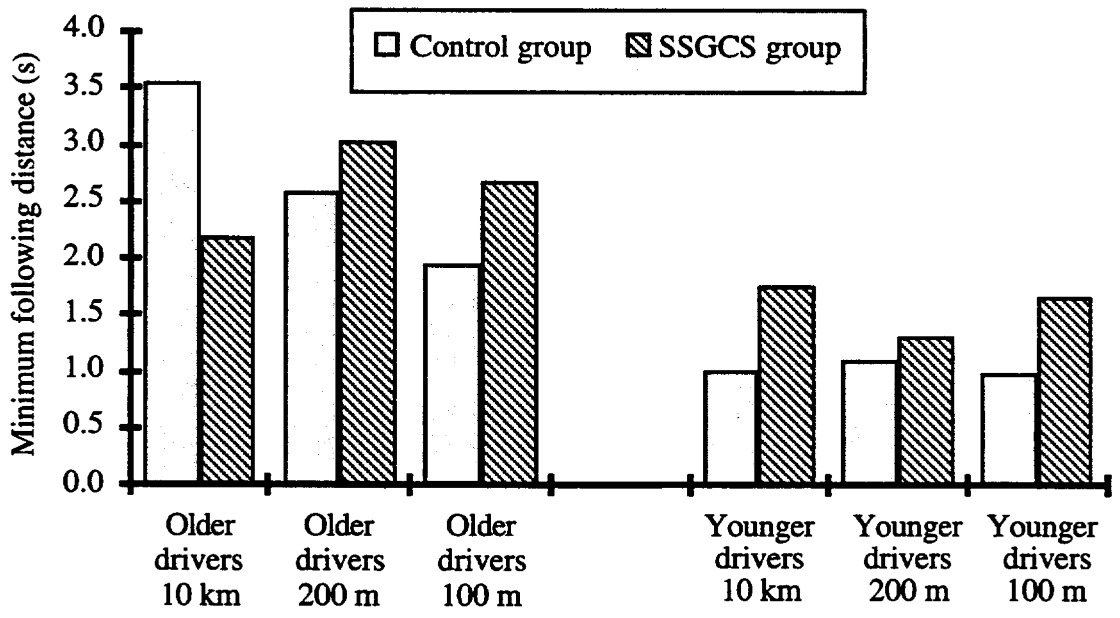

Figure 7. Minimum following distance (in seconds) as a function of age and visibility for the control-group drivers and the minimum gap setting for the experimental-group drivers while they were using the SSGCS.

Effect of Age. If the six columns to the left of figure 7 are compared to the six columns to the right, the significant main effect of age on minimum following distance is clearly revealed. The younger drivers had a shorter minimum following distance than the older drivers, whether they were in the experimental group or the control group, at all three visibility levels. Since this main effect is illustrated very clearly in figure 7, and because it is not meaningful to take the average of the minimum setting on the SSGCS, which was the measure obtained from the experimental-group drivers while they were using the SSGCS, and minimum following distance, which was the measure obtained from the control-group drivers, the overall effect of age is not discussed in a separate section in this report.

Effect of Group. There was no overall effect of group on the minimum following distance. The three-way interaction occurred because, as figure 7 shows, for five of the six possible combinations of age and visibility, the average minimum following distance for control-group drivers was shorter than the smallest gap set by the experimental-group drivers. For the sixth combination, with the older drivers when the visibility was clear, the minimum following distance for the older control-group drivers was considerably longer than the shortest gap selected by the older experimental-group drivers: the minimum following distances were 3.6 s and 2.2 s, respectively.

Effect of Visibility. The effect of visibility is also complex. For the older control-group drivers there was a decrease in minimum following distance as the visibility deteriorated, when following distance is measured in time. However, for the younger control-group drivers, there was virtually no change in the minimum following distance across the three visibility levels, when following distance is measured in time. Thus, although they reduced their average velocity as visibility decreased, the younger drivers' following behavior indicated they were being neither more nor less cautious with changes in visibility. However, in spite of the fact that the older drivers drove more cautiously throughout the journey than the younger drivers, their driving was less cautious in the reduced-visibility conditions than it had been when the visibility was clear.

For both the younger and older experimental-group drivers, there was no obvious relationship between the minimum gap setting and visibility. However, it is worth pointing out that use of the SSGCS resulted in the average minimum gap settings being longer for the experimental-group drivers than the minimum following distances—with the exception of the older drivers when the visibility was clear.

Actual Gap, Gap Setting, and Use of the SSGCS

Because the experimental-group drivers were asked to set the gap in seconds, the actual gap of both the experimental- and control-group drivers, as well as the gap setting, were measured in seconds for the purposes of this analysis.

There are two ways of considering the average gap of drivers who used the SSGCS. First, and most obviously, it is possible to directly measure the actual gap between the driver's car and the vehicle ahead. The actual gap, while to some extent reflecting the gap setting chosen by the driver, will also be heavily influenced by the driver's speed setting and by the dynamic nature of driving. For example, if a vehicle pulled into or out of the lane directly ahead of the driver, or if the vehicle ahead accelerated or decelerated, the SSGCS may have increased or decreased the speed of the driver's car and changed the actual gap. Second, it is possible to measure the average gap setting. It should be noted that the average gap setting will always be shorter than the actual gap. This is because, while at times during the journey the actual gap may be longer than or equal to the gap setting, it can never be shorter than the setting.

Both measures are examined here. They were compared with the actual gap of the control-group drivers, as long as that gap fell within the range to which the SSGCS was limited (i.e., it was equal to or greater than 0.5 s and equal to or less than 5.0 s). The results of the two ANOVA's are summarized in table 8. The complete summaries for these ANOVA's are presented in tables 45 and 46 in appendix 7.

Table 8. Summary showing only the statistically significant effects found by the two ANOVA's used to determine if the average actual gap or the average gap setting were affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

	p Value	
Source	Average Actual Gap	Average Gap Setting
Group	0.0311	—
Age	0.0007	0.0025

The table indicates that two variables had statistically significant effects on the average actual gap, the group that the driver was in and the age of the driver. However, when the actual gap of the control-group drivers was compared with the average gap setting for the drivers in the experimental group, only the age of the driver made a statistically significant difference.

Group. Figure 8 illustrates the difference in average actual gaps of the control-group drivers and of the experimental-group drivers when they were using the SSGCS.

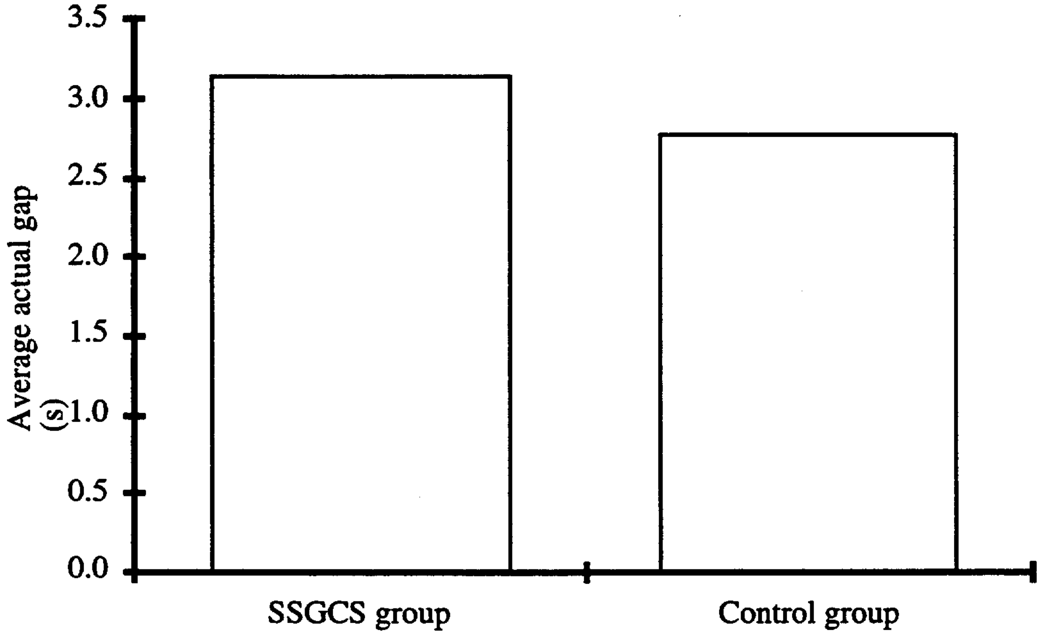

Figure 8. Average actual gap in seconds for the experimental-group drivers while they were using the SSGCS and for the control-group drivers.

As can be seen in figure 8, the average actual gap between the driver's car and the vehicle directly ahead was greater for the experimental-group drivers when they were using the SSGCS than the average actual gap for the control-group drivers, 3.2 s and 2.8 s, respectively.

It should be noted that, in the second analysis shown in table 8, the difference between the gap that was set by the experimental-group drivers and the control-group drivers was not significant.

The Age of the Driver. Figure 9 illustrates the difference in the actual gaps of younger and older drivers, averaged over the control- and experimental-group drivers.

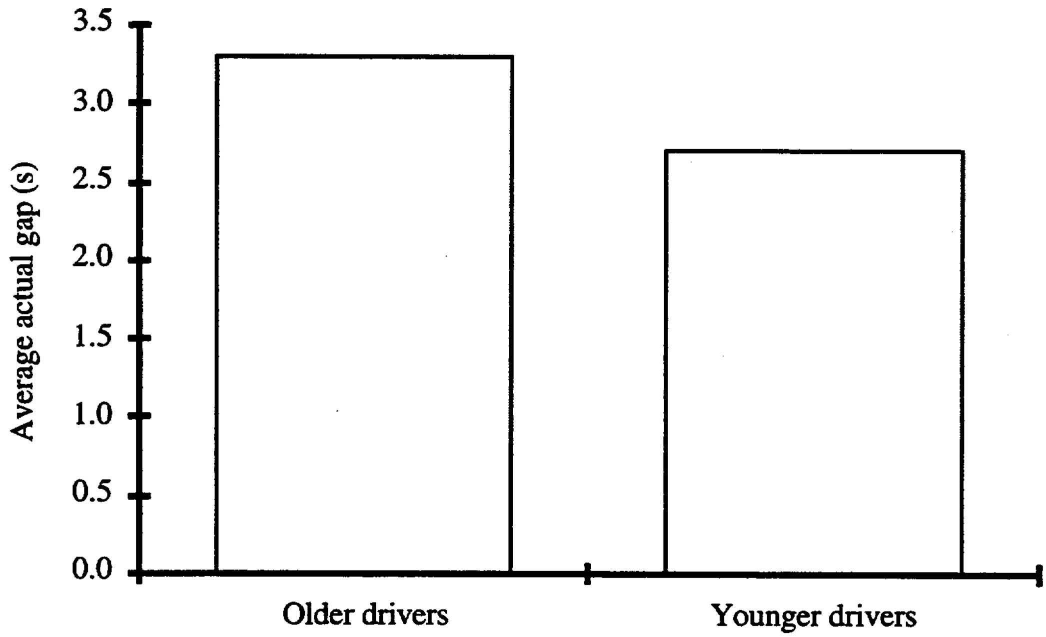

Figure 9. Average actual gap in seconds for older and younger drivers.

As figure 9 illustrates, the older drivers kept their car further behind the vehicle directly ahead than the younger drivers did. The average actual gaps were 3.3 s and 2.7 s for the older and younger drivers, respectively.

A statistically significant difference between the older and younger drivers can also be found when the gap set by the drivers in the experimental group is compared with the actual gap of the control-group drivers. This difference is shown in figure 10. The averages were 3.2 s and 2.4 s for the older and younger drivers, respectively.

It should be noted that, while the average values shown in figures 9 and 10 were derived from the experimental- and control-group drivers, only the data from the experimental-group drivers changed from one graph to the other. The data from the control-group drivers, which were actual gap data, were identical in both analyses. When only the data of the experimental-group drivers are used, the average gap settings for the older and younger drivers are found to have been 3.3 s and 2.5 s, respectively.

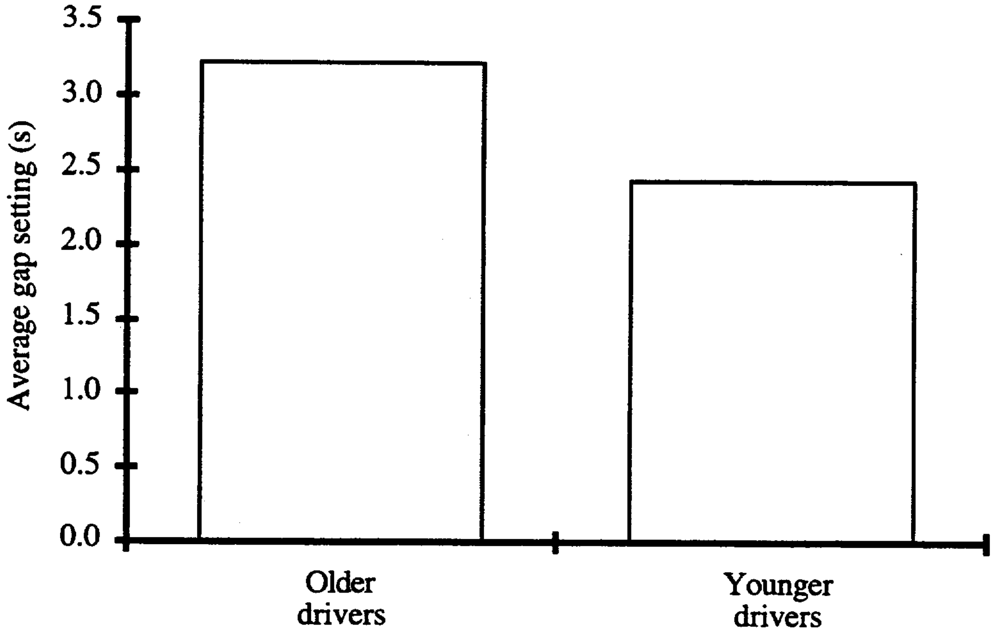

Figure 10. Average gap setting for the experimental-group drivers and actual gap of the control-group drivers as a function of the driver's age.

Summary of the Effects of Driving While Using the SSGCS

The driving performance of the drivers in the control group was compared with that of the drivers in the experimental group while they were using the SSGCS. The results were as follows:

- Using the SSGCS had no effect on the average velocity.
- When the visibility was reduced to 200 m (656 ft) or 100 m (328 ft), whether the drivers were young or old, the minimum following distance was longer for the experimental-group drivers when they were using the SSGCS than it was for the control-group drivers. When the visibility was clear and the drivers were young, the minimum following distance was also longer for the experimental-group drivers who used the SSGCS. However, when the visibility was clear and the drivers were old, the minimum following distance was shorter for the experimental-group drivers who used the SSGCS than it was for the control-group drivers, though it should be noted that, in this case, the minimum following distance was still relatively large (2.2 s).
- When the experimental-group drivers used the SSGCS, the average actual gap was longer (3.2 s) than it was for the control-group drivers (2.9 s).

DRIVING WHILE USING ONLY THE CWS

To determine how the driver's performance was affected when he/she was using only the CWS, driving-performance data obtained from drivers using the CWS alone were compared with data from the drivers in the control group.

When the CWS alone was activated, it issued a warning if the driver approached the vehicle ahead too quickly. Unlike the SSGCS, the CWS did not take control of any driving functions. Driving-performance data obtained from the drivers in the experimental group while they were using the CWS alone and from the drivers in the control group were compared using all the lane-keeping, speed-control, and following-distance measures that were listed in table 3. These comparisons were conducted using ANOVA's, with the results reported below.

Steering Instability While Using Only the CWS

Steering instability, the first of the lane-keeping measures listed in table 3, provides a measure of the variability in steering around the line of best fit of the track of the vehicle. The results of the ANOVA conducted to compare the steering instability of the control group with that of the experimental group when using the CWS alone are presented in table 9. The complete summary for this ANOVA is presented as table 47 in appendix 7.

Table 9. Summary showing only the statistically significant effects found by the ANOVA used to determine if steering instability was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group	0.0381
Traffic density	0.0268

As the table indicates, steering instability was affected by the density of traffic and by whether the driver was in the control or the experimental group.

Traffic Density. The effect of traffic density on steering instability is shown in figure 11.

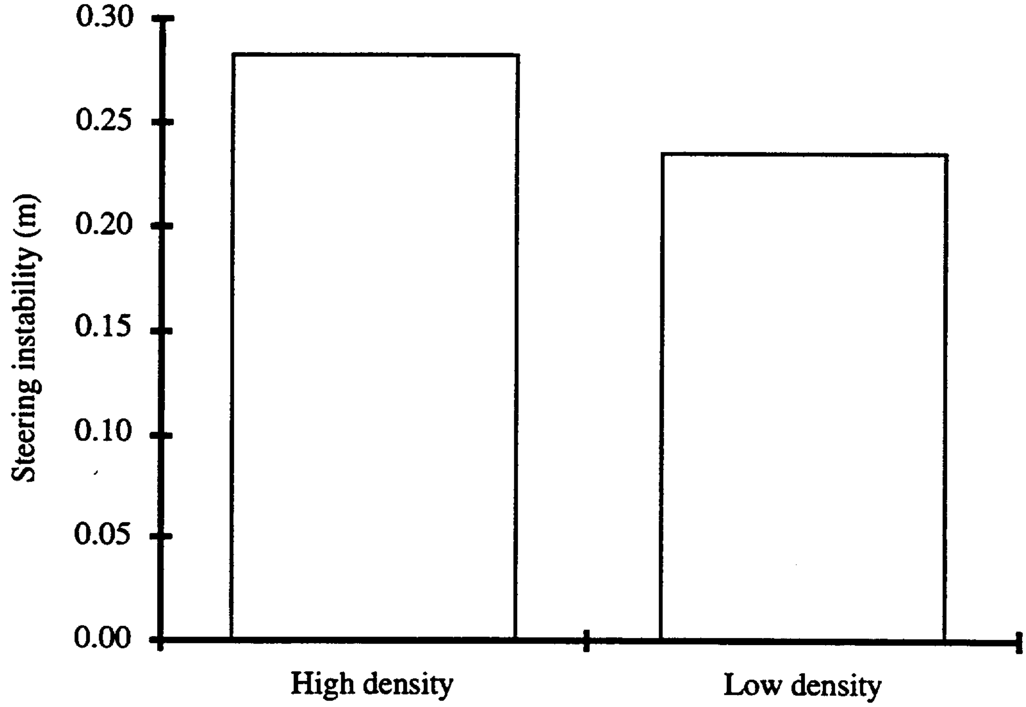

Figure 11. Steering instability in meters for drivers traveling in either high- or low-density traffic.

As the figure illustrates, there was greater steering instability when the traffic density was 12.42 v/km/ln (20 v/mi/ln) than when it was 6.21 v/km/ln (10 v/mi/ln). The steering instability was 0.28 m (0.92 ft) for drivers who drove in the higher density traffic and 0.24 m (0.79 ft) for those who drove in the less-dense traffic.

Group. The difference in steering instability for drivers in the control group and those in the experimental group when they were using the CWS are shown in figure 12.

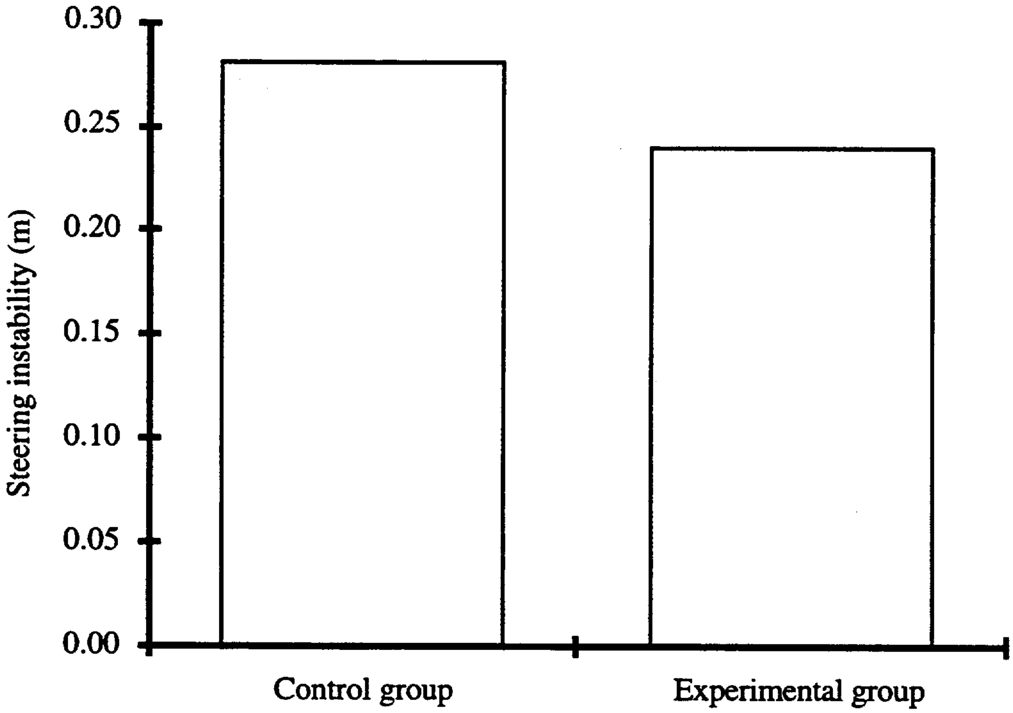

Figure 12. Average steering instability of drivers in the experimental group when they were using the CWS and drivers in the control group.

Figure 12 shows that there was more steering instability for control-group drivers than there was for experimental-group drivers when the latter were using the CWS. The steering instability was 0.28 m (0.92 ft) for control-group drivers and 0.24 m (0.79 ft) for those in the experimental group.

Steering Oscillations While Using Only the CWS

The number of steering oscillations is the second of the lane-keeping measures listed in table 3. They occur whenever the track of the vehicle crosses the line of best fit. The frequency with which they occur is measured by determining the number of times that the track of the vehicle crosses the line of best fit/min. To compare the steering oscillations of the control group with those of the experimental group when they were using the CWS alone, an ANOVA was conducted, with the result shown in table 10. The complete summary for this ANOVA is presented as table 48 in appendix 7.

Table 10. Summary showing only the statistically significant effects found by the ANOVA used to determine if the number of steering oscillations/min was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group (G)	0.0001
Visibility level (V)	0.0001
Group by age (A)	0.0497
G x V	0.0044
A x V	0.0492
G x A x V	0.0225
Group by age by traffic density by visibility level	0.0395

As illustrated in table 10, both the group and the visibility level had statistically significant effects on number of steering oscillations/min. In addition, there were three significant two-way interactions, one significant three-way interaction, and one significant four-way interaction. Since it subsumes all the other effects, the four-way interaction is discussed first. Then this is followed by brief discussions of the two main effects.

Interaction of Group, Age, Traffic Density, and Visibility. The four-way interaction is depicted in figure 13.

Group and Visibility Effects. The two significant main effects of group and visibility can be seen in figure 13. The effect of the group is revealed by directly comparing the 12 pairs of columns in the figure. In each case, the number of steering oscillations was greater for the drivers in the experimental group than it was for the control-group drivers. While the magnitude of the difference between the two groups was greater in some cases than others (it was greatest for the older drivers in the higher density traffic and the 200-m (656-ft) visibility, and smallest for the older drivers in the higher density traffic and clear visibility), it always favored the experimental group rather than the control group. This effect is discussed in the section below on "Group."

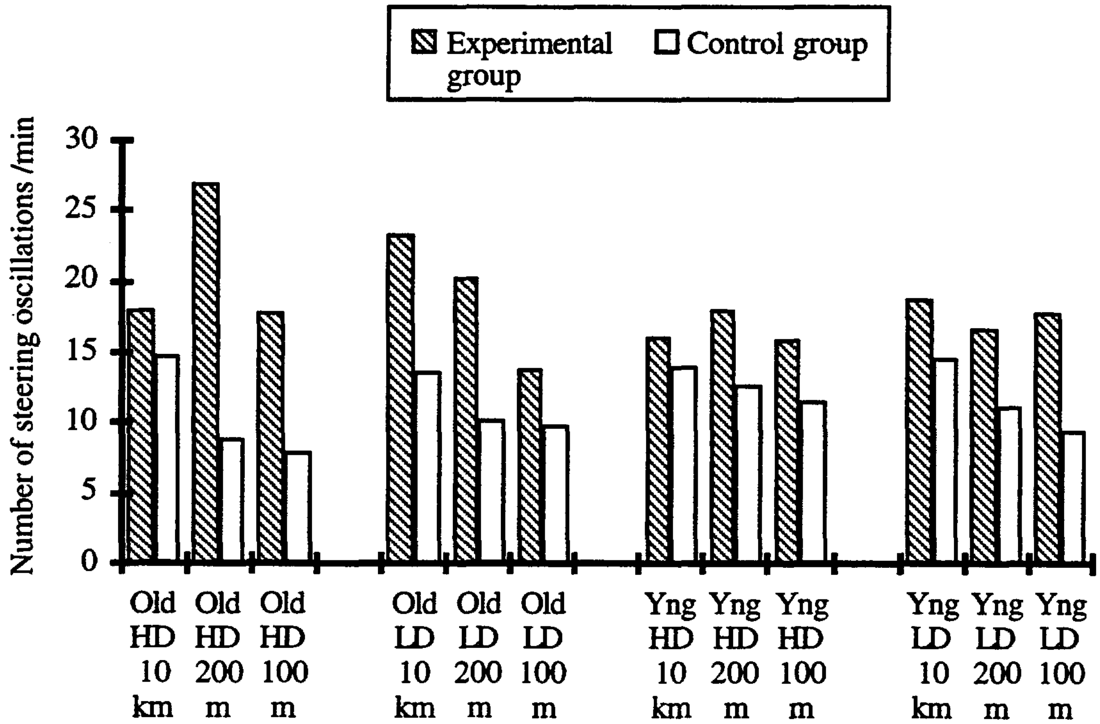

Figure 13. Number of steering oscillations/min as a function of age, density, and visibility for drivers in the experimental group when they used the CWS and in the control group. [HD = high density, LD = low density.]

The main effect of visibility can also be seen in figure 13. For all the control-group drivers, older and younger driving in high- and low-density traffic, the number of oscillations decreased with decreasing visibility. The same effect can be seen for the older experimental-group drivers in the low-density traffic. However, this pattern is less clear for the remaining three groups: each of them has one result that breaks this pattern. For both older and younger drivers in the high-density traffic to maintain the same pattern, the number of oscillations should have been greater when the visibility was clear; for younger drivers in low-density traffic to maintain the pattern, the number of oscillations should have been smaller when the visibility was 100 m (328 ft). The effect of visibility is discussed in the section below on "Visibility."

Effect of the Age of the Driver. The effects of age are best described in terms of the interaction with group. For drivers in the experimental group, those who were older had more steering oscillations than those who were younger in five out of six cases; for drivers in the control group, those who were older had fewer steering oscillations than those who were younger in four out of six cases.

Effect of Traffic Density. The effect of traffic density was mixed. In 6 of 12 cases, the number of steering oscillations was greater for the high-density cases; in the remaining 6 cases the number of steering oscillations was smaller for the high-density cases.

Group. The statistically significant main effect of group that was mentioned previously is illustrated in figure 14.

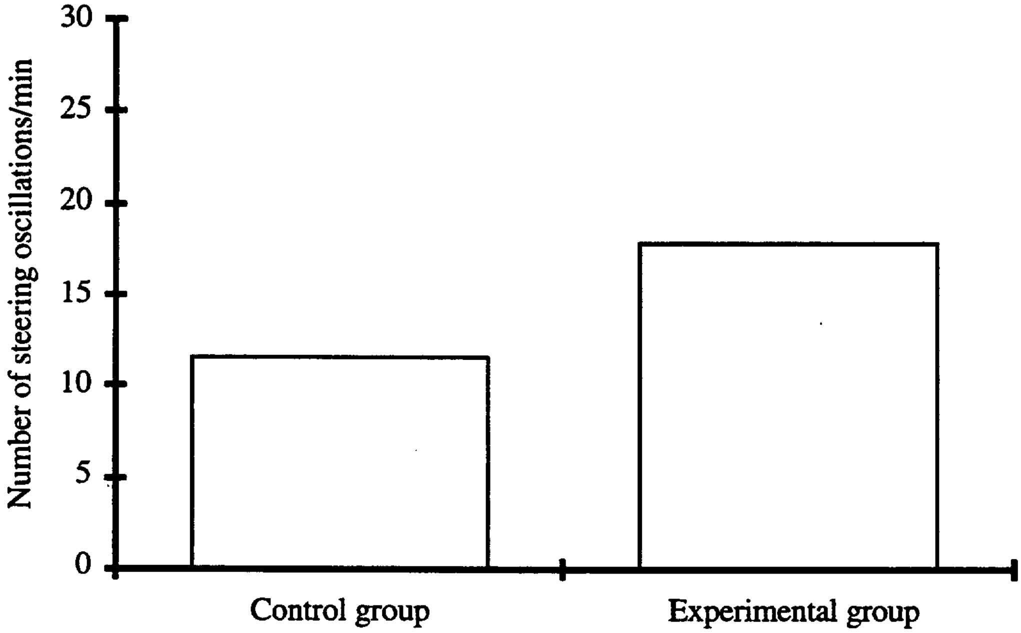

Figure 14. Number of steering oscillations/min for drivers in the experimental group when they used the CWS and in the control group.

As can be seen from figure 14, there were fewer steering oscillations for drivers in the control group than there were for those in the experimental group. On average there were 11.6 steering oscillations/min for control-group drivers and 18.0 oscillations/min for the experimental-group drivers.

Visibility. The statistically significant main effect of visibility mentioned above is illustrated in figure 15.

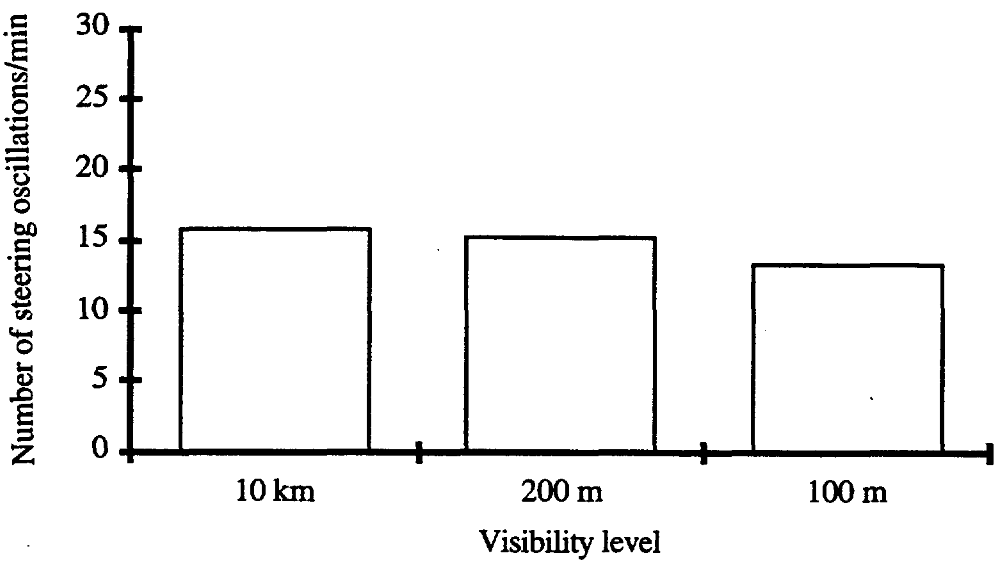

Figure 15. Number of steering oscillations per minute as a function of visibility level.

Figure 15 shows the tendency, already mentioned in the discussion of the four-way interaction above, for the number of steering oscillations/min to decrease with the visibility. As the visibility dropped from 10 km (6.21 mi) to 100 m (656 ft), the number of steering oscillations dropped from 15.9/min to 13.4/min.

Average Velocity While Using Only the CWS

Average velocity is the first of the three velocity-control measures listed in table 3. The results of the ANOVA conducted to determine the effect on the average velocity of using the CWS alone are shown in table 11. The complete summary for this ANOVA is presented as table 49 in appendix 7.

As table 11 indicates, the age of the driver and the visibility level both had statistically significant effects on the average velocity. There was also a significant interaction between these two variables, and the main effects are best discussed in terms of that interaction. In addition, there were two other two-way interactions; both also involved the level of visibility, with group and traffic density

Table 11. Summary showing only the statistically significant effects found by the ANOVA used to determine if the average velocity was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age (A)	0.0001
Visibility level (V)	0.0001
Group by visibility level	0.0254
Traffic density by visibility level	0.0495
A x V	0.0026

Interaction of Visibility and Group. The interaction between the visibility level and group is explored in figure 16.

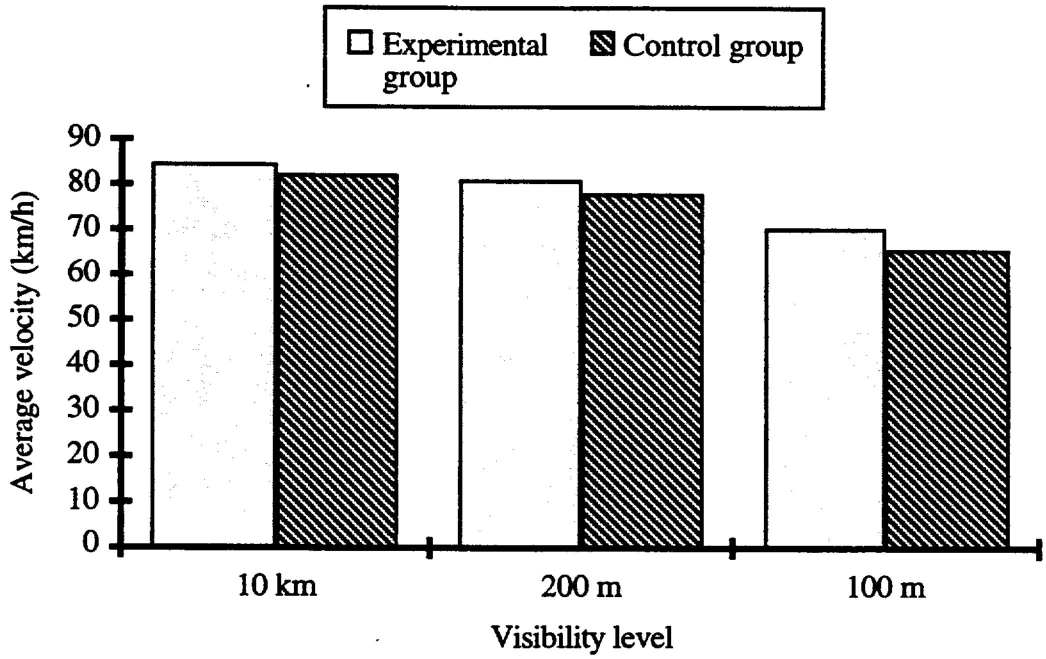

Figure 16. Average velocity as a function of visibility for drivers in the experimental group when using the CWS alone and in the control group.

Inspection of figure 16 shows the main effect of visibility on average velocity: it decreased as the visibility decreased from 10 km (6.21 mi) via 200 m (656 ft) to 100 m (328 ft).

The figure also shows the interaction between visibility and group. The average velocity for experimental-group drivers was greater than it was for the control-group drivers at all three visibilities. However, the average velocity was only 2.54 km/h (1.58 mi/h) greater for the experimental-group drivers when there was clear visibility; whereas, when the visibility had decreased to 100 m (328 ft), the average velocity was 4.75 km/h (2.95 mi/h) greater for the experimental-group drivers.

Interaction of Visibility and Traffic Density. The interaction between the visibility level and traffic density is explored in figure 17. Like figure 16, figure 17 clearly shows the main effect of visibility, with average velocity decreasing with the visibility level. It also shows that the interaction between visibility and density occurs because, while the average velocity was greater for the drivers driving in higher density traffic than those driving in lower density traffic, the

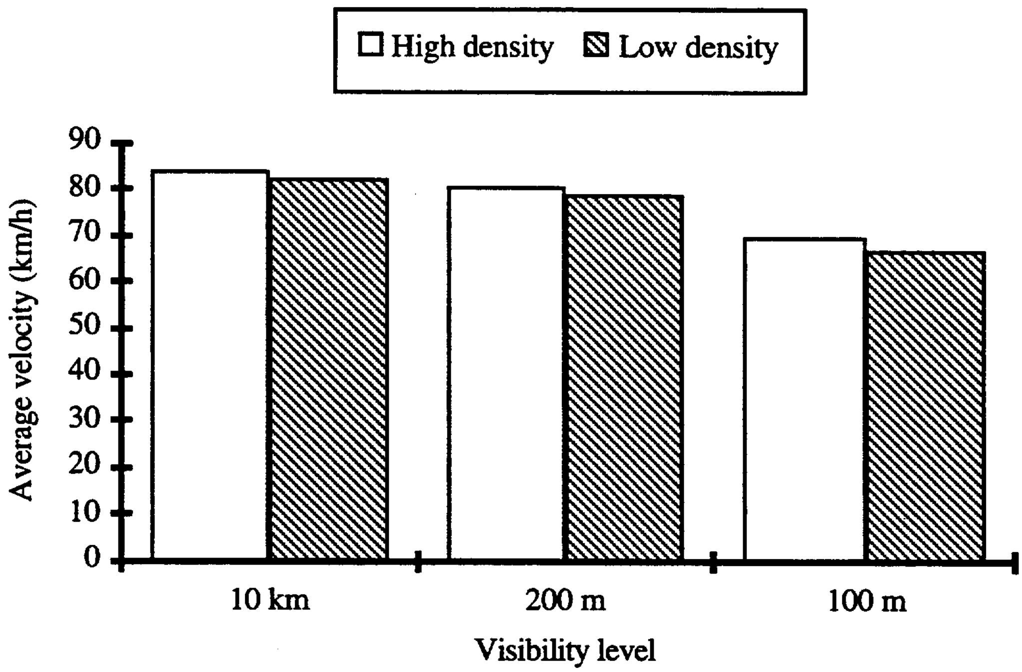

Figure 17. Average velocity as a function of visibility level and traffic density.

average velocity was only 1.74 km/h (1.08 mi/h) and 1.61 km/h (1.00 mi/h) greater for those who drove in high density traffic when the visibility was 10 km (6.21 mi) and 200 m (656 ft), respectively; whereas, when the visibility decreased to 100 m (328 ft), the average velocity was 2.59 km/h (1.61 mi/h) greater for the high-density group.

Interaction of Visibility and the Age of the Driver. The interaction between the visibility level and the age of the driver is illustrated in figure 18.

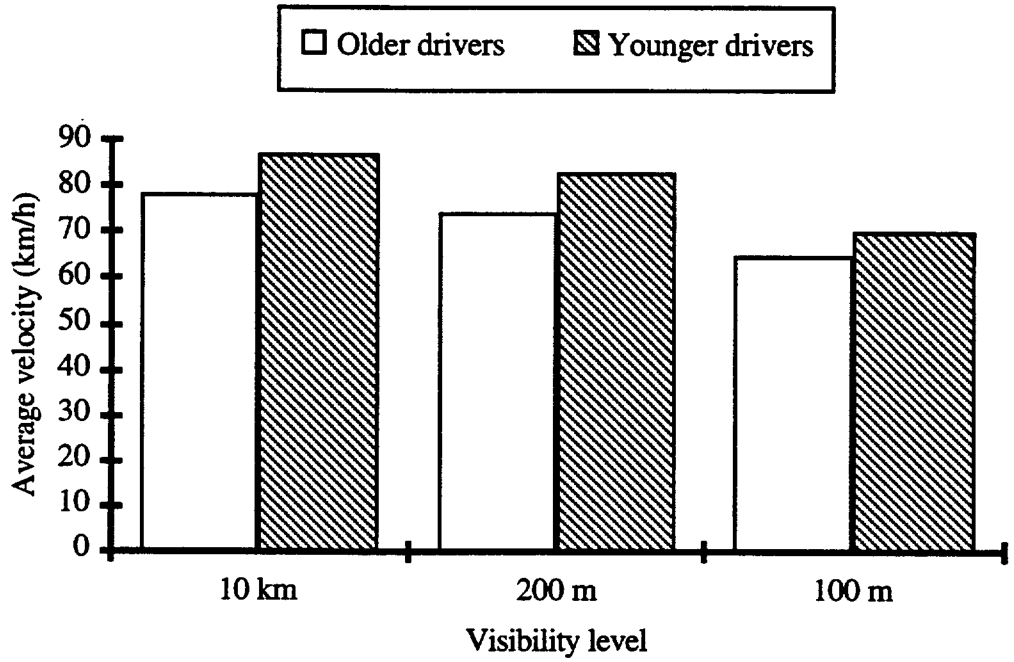

Figure 18. Average velocity as a function of visibility level — older and younger drivers.

Like figures 16 and 17, figure 18 clearly shows the main effect of visibility, with average velocity decreasing with the visibility level. It also clearly shows the main effect of the driver's age: at all three visibility levels, the average velocity of older drivers is less than that of younger drivers. The interaction between the two variables occurs because the difference in average velocity between younger and older drivers is smaller when the visibility is 100 m (328 ft) than it is when the visibility is 200 m (656 ft) or clear.

Visibility. The overall effect of the level of visibility is shown in figure 19.

Figure 19 indicates that the average velocity decreased with the visibility. When the visibility was clear, the average velocity was 83.4 km/h (51.8 mi/h). In the next section of the journey, the visibility was 200 m (656 ft) and the velocity dropped to 79.8 km/h (49.6 mi/h), which is 95.6 percent of the velocity in the clear condition. This is very similar to the 93.7 percent (calculated from Hawkins' observational data for this visibility) that was used to determine the

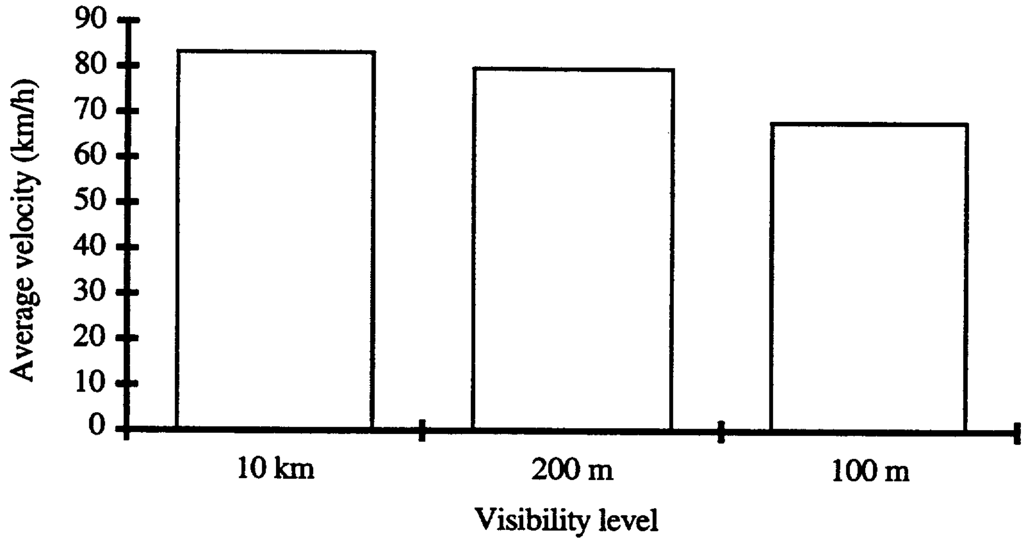

Figure 19. Average velocity as a function of visibility level.

speed of the other vehicles present on the expressway in this experiment.(16) In the third section of the journey, when the visibility deteriorated further to 100 m (328 ft), the average velocity dropped again, to 68.3 km/h (42.4 mi/h). This time the velocity was 81.9 percent of that in the clear condition, which again is similar to the 77.2 percent calculated from the data reported by Hawkins for this visibility.(16)

Velocity Instability While Using Only the CWS

The second of the three velocity-control measures listed in table 3 is velocity instability. Velocity instability is a measure of the variability in velocity that occurs when the driver is driving along the lane. Mathematically, it is the residual standard deviation of the actual instantaneous velocities of the vehicle about the line of best fit. The results of the ANOVA that was conducted to determine the effect on velocity instability of using the CWS alone are shown in table 12. The complete summary for this ANOVA is presented as table 50 in appendix 7.

As shown in table 12, the group to which the drivers belonged had a statistically significant effect on the velocity instability. This variable was also involved in two significant interactions: a two-way interaction with visibility level and a three-way interaction with visibility level and the age of the driver.

Table 12. Summary showing only the statistically significant effects found by the ANOVA used to determine if the velocity instability was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group	0.0001
Group by visibility level	0.0179
Group by age by visibility level	0.0091

Interaction of Group, Visibility, and Age. This three-way interaction is explored in figure 20.

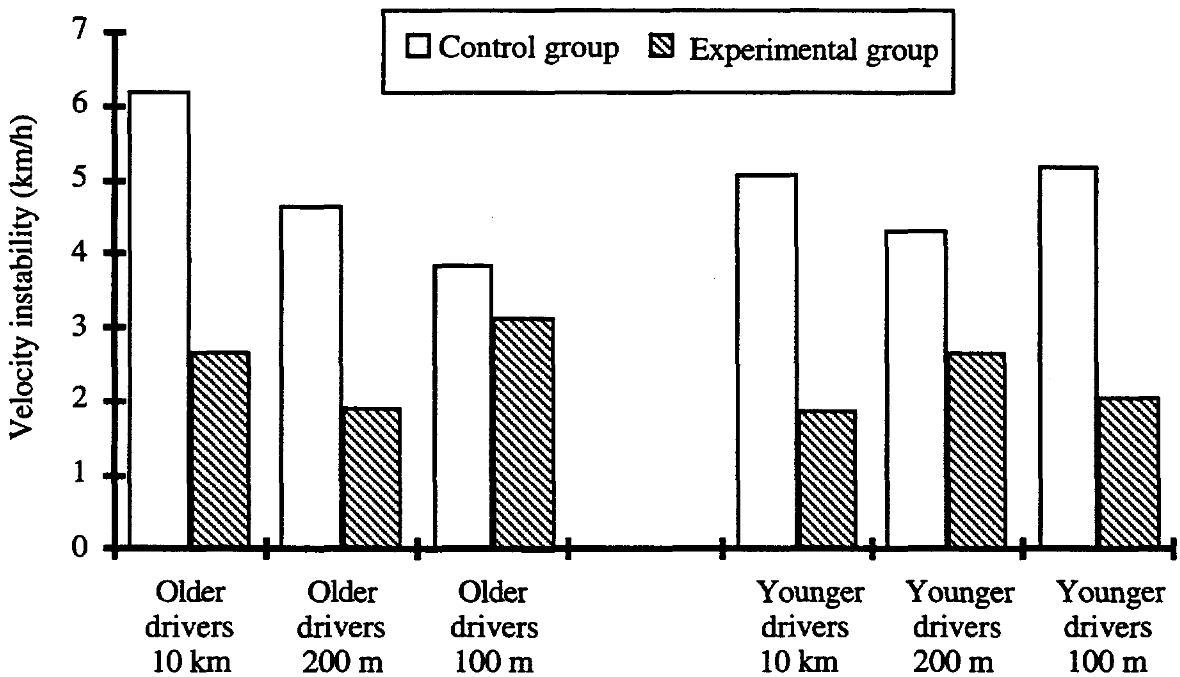

Figure 20. Velocity instability as a function of age, visibility level, and group.

Effect of Group. The effect of group can be seen by comparing adjacent pairs of columns across figure 20. The velocity instability is greater for the control-group drivers than it is for the experimental-group drivers who were using the CWS alone in all six of the possible comparisons. This main effect is discussed further in the following subsection of the report.

Effect of Visibility and Age. The effects of the remaining two variables involved in the interaction shown in figure 20 are mixed. The level of visibility has no consistent effect on velocity instability. For example, for the older control-group drivers, velocity instability was greatest when the visibility was clear; for the older experimental-group drivers and the younger control-group drivers, velocity instability was greatest when the visibility was 100 m (328 ft); and for the younger experimental-group drivers, velocity instability was greatest when the visibility was 200 m (656 ft).

Similarly, the age of the driver did not have a consistent effect on velocity instability; it was higher for the older control-group drivers when the visibility was clear or 200 m (656 ft) and for the older experimental-group drivers when the visibility was clear or 100 m (328 ft); it was lower for the older control-group drivers when the visibility was 100 m (328 ft) and for the older experimental-group drivers when the visibility was 200 m (656 ft).

Group. As mentioned above, there was a clear effect of group on the velocity instability, as illustrated in figure 21.

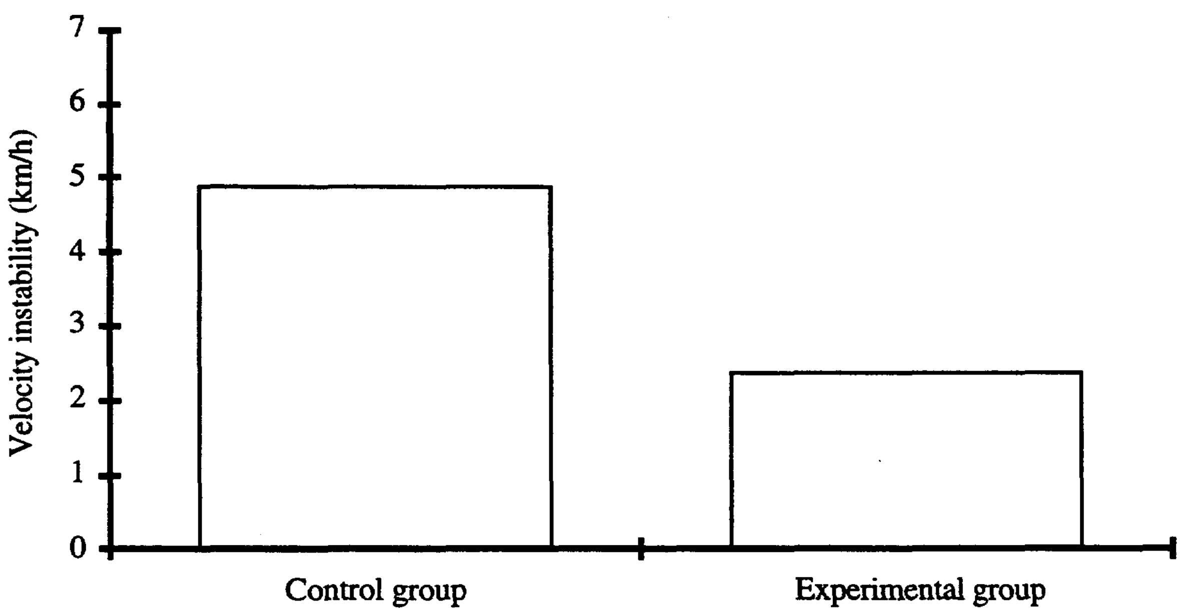

Figure 21. Velocity instability for the experimental-group drivers using the CWS alone and the control-group drivers.

As figure 21 shows, there was twice as much velocity instability for drivers in the control group than there was for drivers in the experimental group who were using the CWS alone. The velocity instability was 4.9 km/h (3.0 mi/h) for the control-group drivers and 2.4 km/h (1.5 mi/h) for the experimental-group drivers.

Number of Velocity Fluctuations While Using Only the CWS

The number of velocity fluctuations is the third of the velocity-control measures listed in table 3. Velocity fluctuations are measured by determining the number of times per minute that the plot of the actual velocities of the vehicle crossed the velocity line of best fit. The results of the ANOVA conducted to determine the effect on velocity instability of using the CWS alone are shown in table 13. The complete summary for this ANOVA is presented as table 51 in appendix 7.

Table 13. Summary showing only the statistically significant effects found by the ANOVA used to determine if the number of velocity fluctuations was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group (G)	0.0001
Age (A) by visibility level (V)	0.0496
Age by traffic density (D) by visibility level	0.0197
G x A x V	0.0381
G x D x V	0.0471
G x A x D x V	0.0230

Table 13 shows that group had a statistically significant effect on the number of velocity fluctuations/min. There were also five statistically significant interactions, one of which was a four-way interaction that subsumes all the other effects, and is discussed first. Then this is followed by brief discussions of the main effects of group.

Interaction of Group, Age, Traffic Density, and Visibility. The four-way interaction is depicted in figure 22.

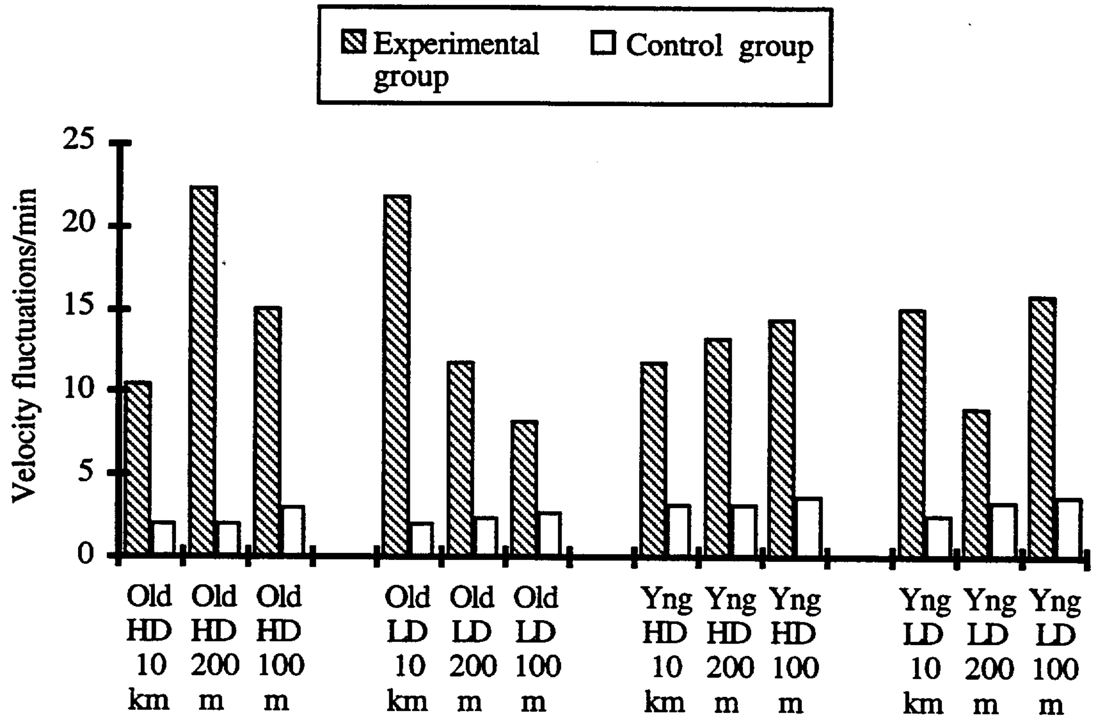

Figure 22. Number of velocity fluctuations/min as a function of age, visibility level, and traffic density. [HD = high density, LD = low density.]

Effect of Group. Figure 22 shows very clearly the significant group main effect. The drivers in the experimental group have many more velocity fluctuations than the control-group drivers. This effect is discussed further in the next subsection of the report.

Effect of the Age of the Driver. It can be seen from figure 22 that, while the older drivers in the experimental group have more fluctuations/min than the younger drivers in the experimental group in four out of six cases, the older drivers in the control group have fewer fluctuations/min than the younger control-group drivers in all six cases.

Effect of Traffic Density. The effect of traffic density is mixed. In 7 out of 12 cases shown in figure 22 there are more velocity fluctuations with the higher traffic density than there are with the lower, while in the remaining 5 cases there are fewer velocity fluctuations with the higher traffic density.

Effect of Visibility. Figure 22 shows that, for drivers in the control group, the number of velocity fluctuations increased as the visibility decreased. A similar pattern was seen with the younger drivers in the experimental group who were using the CWS alone when the traffic density was high. However, for the younger drivers in the experimental group who drove in low-density traffic, and for the older drivers in the experimental group who drove with both traffic densities, there were different relationships between the number of fluctuations and the level of visibility.

Group. The large effect of group on the number of velocity fluctuations is shown in figure 23.

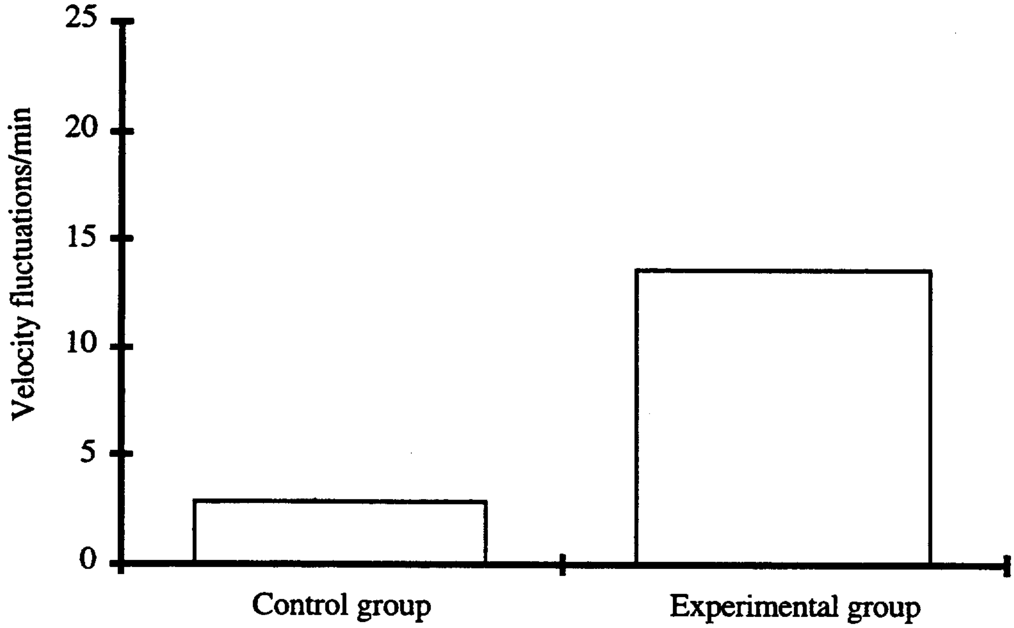

Figure 23. Number of velocity fluctuations/min for both the experimental-group drivers who used the CWS alone and the control-group drivers.

As figure 23 shows, the drivers in the experimental group who used the CWS alone had four times as many velocity fluctuations as the drivers in the control group. They had 13.6 and 2.9 fluctuations/min, respectively

Minimum Following Distance While Using Only the CWS

Earlier in this report, the measure of minimum following distance used for the drivers in the experimental group who were using the SSGCS was the shortest gap setting selected by these drivers. In contrast, for the drivers in the experimental group who were using the CWS alone, the minimum following distance was derived in the same way as it was for the drivers in the control group, and as it was in earlier experiments in this series.(6,8) The minimum following distance was obtained by continuously calculating the distance between the driver's car and the vehicle ahead, and then applying a set of criteria to these data to determine the minimum following distance that the driver actually selected.[6]

Unlike its use earlier in this report, for the experimental-group drivers when they were using the SSGCS, but similar to its use in the previous experiments in this series, the minimum following distance that was used here for experimental-group drivers when they were using the CWS alone was measured in meters (and feet).(6,8)

An ANOVA was conducted in order to compare the minimum following distance of the drivers in the control group with that of the drivers in the experimental group while they were using only the CWS. Table 14 shows the statistically significant main effects and interactions. The complete summary for this ANOVA is presented as table 52 in appendix 7.

As table 14 shows, three variables, the age of the driver, the traffic density, and the visibility level, had statistically significant effects on the minimum following distance. There were also two interactions, a two-way interaction between age and visibility level and a three-way interaction among age, density of traffic, and visibility level. It should be noted that there was no group effect on the minimum following distance.

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[6]To determine the minimum following distance for each driver whether the driver was in the control group or in the experimental group, the following procedure was used. First, for each of the three visibility levels, the gap between the front bumper of the driver's car and the back bumper of the vehicle ahead was recorded at 30 Hz. Second, if the driver changed lanes, the data obtained during the lane change were eliminated from consideration. Third, whenever the gap between the driver's vehicle and the vehicle ahead exceeded 440 m (1443 ft), the data were eliminated from consideration. Fourth, if after a break in the data the gap increased continuously, the lowest point was ignored (if the gap was continuously increasing, this may have been because the driver was uncomfortable with the gap and had reduced speed to increase it). Fifth, if before a break in the data the gap decreased continuously, the lowest point was also ignored (if the gap was continuously decreasing, this may have been because the gap was still larger than the minimum following distance that was acceptable to the driver). Sixth, the lowest point was selected. Seventh, it was determined whether there were gap data for at least 10 s around the lowest point—if there were less than 10 s of data, they were discarded. Eighth, the gap data acquired in any period that was 10 s or more were examined—if during this 10-s period the gap exceeded the lowest point by 133 percent, the data were discarded (this is because the lowest point may have occurred because another vehicle moved into the lane ahead of the driver, leaving a gap that was smaller than was acceptable to the driver who, as a result, reduced speed to increase the gap). Ninth, if the data met all the criteria listed above, the lowest point was reported as the minimum following distance for the driver within each visibility level.

Table 14. Summary showing only the statistically significant effects found by the ANOVA used to determine if the minimum following distance (in meters) was affected by group —whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age (A)	0.0018
Density (D)	0.0072
Visibility (V)	0.0058
A x V	0.0022
A x D x V	0.0475

<u>Interaction of Age, Traffic Density, and Visibility.</u> The three-way interaction is shown in figure 24.

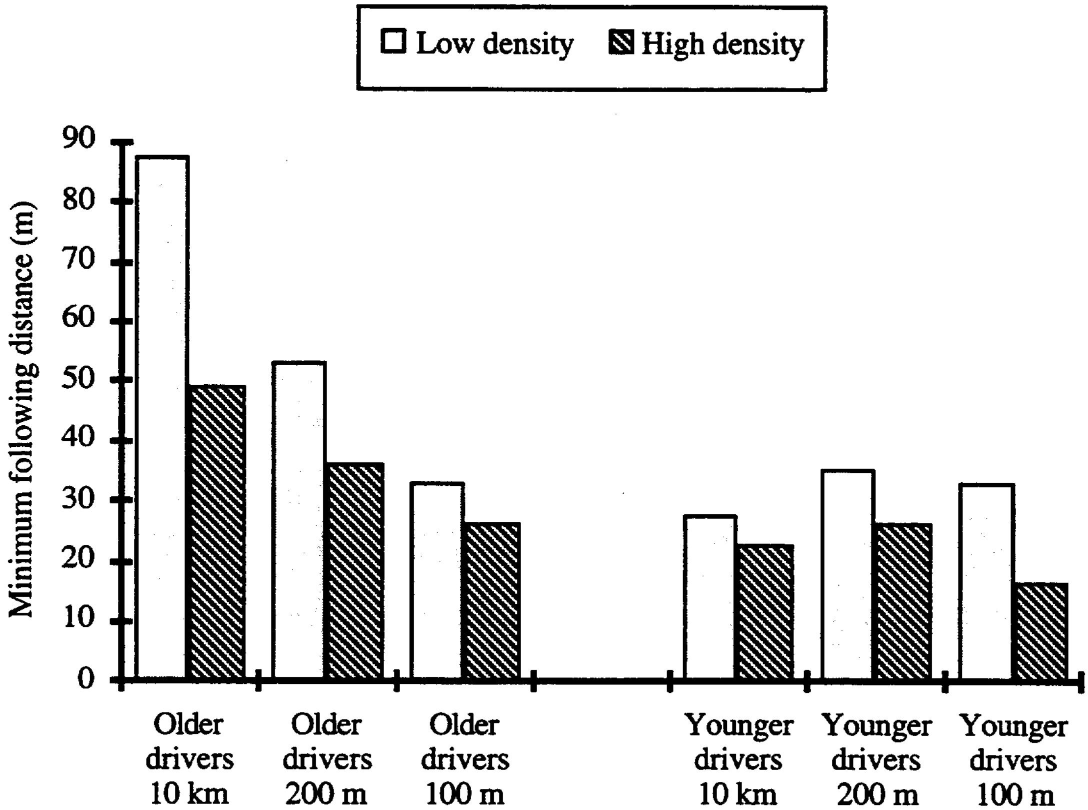

Figure 24. Minimum following distance (in meters) as a function of age, visibility, and traffic density.

The significant age and traffic-density main effects emerge clearly from figure 24, while the effect of the level of visibility on the minimum following distance is less obvious.

Effect of Age. As can be seen in figure 24, the older drivers had considerably longer minimum following distances than the younger drivers at all three visibility levels when the traffic density was 12.42 v/km/ln (20 v/mi/ln), and when the visibility was 10 km (6.21 mi) or 200 m (656 ft) and the traffic density was 6.21 v/km/ln (10 v/mi/ln). The only exception occurred when the visibility was 100 m (328 ft) and the traffic density was 6.21 v/km/ln (10 v/mi/ln); in this case, the minimum following distances were virtually the same for the older and younger drivers. The effect of the age of the driver is discussed later.

Effect of Traffic Density. The effect of traffic density on minimum following distance can be seen even more clearly than that of age in figure 24. In all six of the possible comparisons, the minimum following distance was longer when the traffic density was low. This main effect will be discussed again later.

Effect of Visibility. From figure 24, it is clear that, for the older drivers in both low- and high-density traffic, the minimum following distance decreases with decreasing visibility. However, for the younger drivers, there was a different pattern: for both density conditions, their longest minimum following distance was at 200-m (656-ft) visibility.

<u>Age of the Driver.</u> As mentioned above, the age of the driver had a statistically significant effect on the minimum following distance, as is illustrated in figure 25. Figure 25 shows that the mean minimum following distance was considerably larger for older drivers than it was for younger drivers; the distances were 47.2 m (154.7 ft) and 26.5 m (86.8 ft), respectively.

<u>Traffic Density.</u> The effect of the traffic density on the minimum following distance is illustrated in figure 26. It was longer for drivers who drove in lower density traffic; the minimum following distances were 42.6 m (139.7 ft) for the lower density and 27.7 m (90.7 ft) for the higher density.

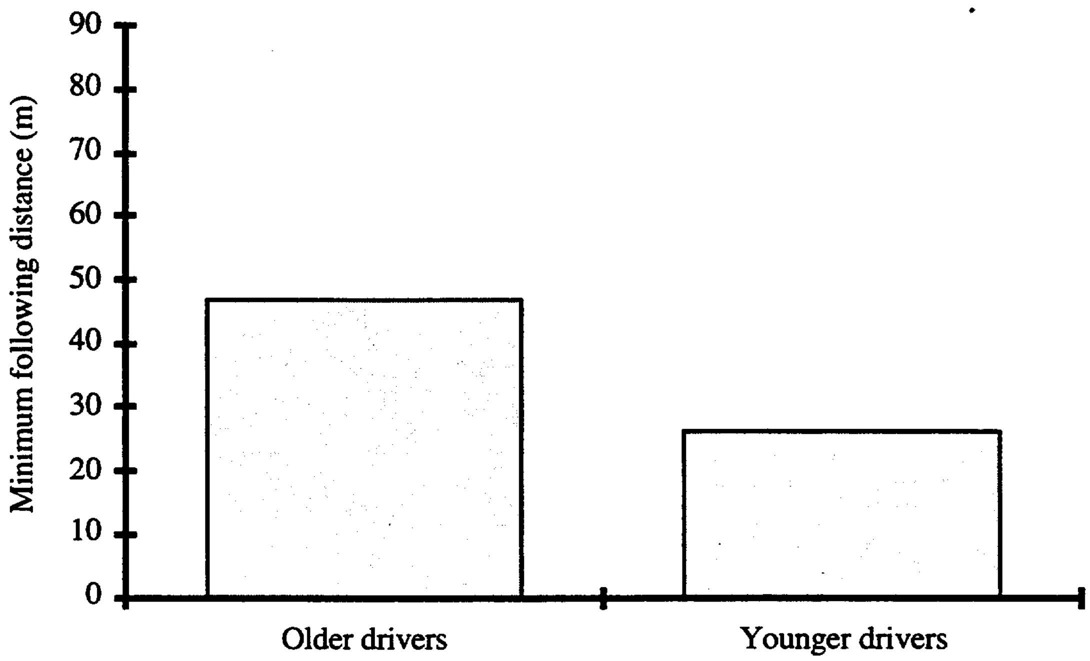

Figure 25. Minimum following distance in meters for older and younger drivers.

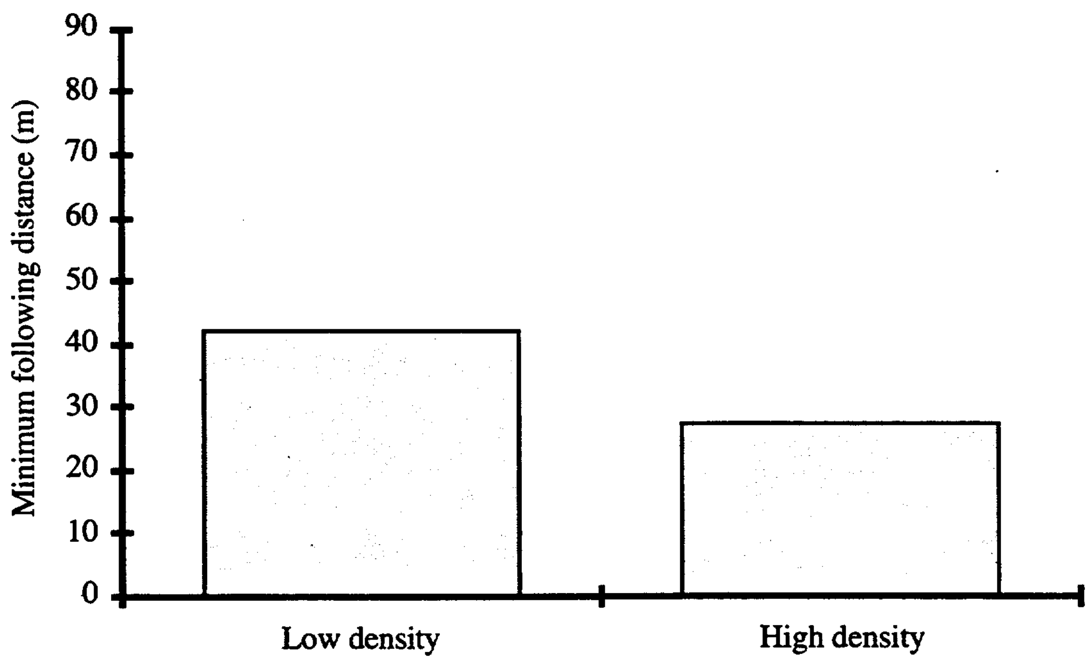

Figure 26. Minimum following distance as a function of traffic density.

Visibility. The effect of the level of visibility on the minimum following distance is illustrated in figure 27.

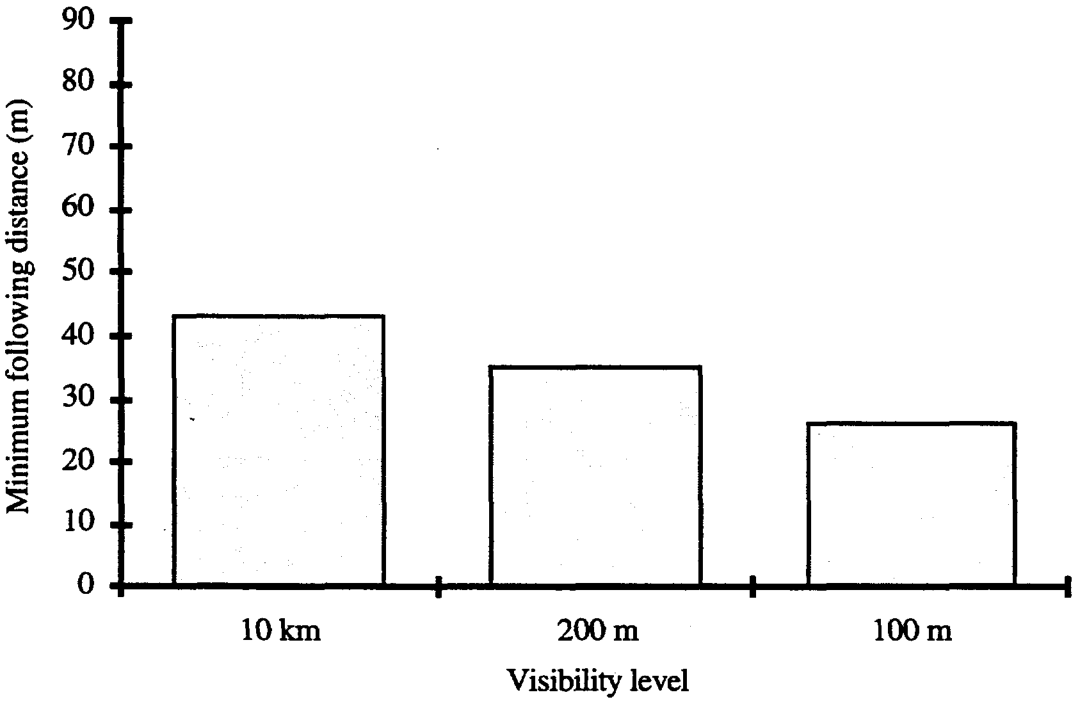

Figure 27. Minimum following distance as a function of visibility level.

Figure 27 shows that, overall, the minimum following distance decreased as the visibility level decreased. This replicates the pattern seen earlier, in figure 24, for the older drivers. However, as the latter figure also showed, the minimum following distance for the younger drivers did not fit this pattern.

Average Actual Gap While Using Only the CWS

The average actual gap provides a second measure of following distance. An ANOVA was used to compare the average actual gap between the driver's car and the vehicle ahead for drivers in the experimental group while using only the CWS and the control-group drivers, with the result shown in table 15. The complete summary for this ANOVA is presented as table 53 in appendix 7.

Table 15. Summary showing only the statistically significant effects found by the ANOVA used to determine if the average actual gap was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age	0.0031

As can be seen from table 15, only one variable, the age of the driver, had a statistically significant effect on the average actual gap. It is discussed below.

<u>Age of the Driver.</u> Figure 28 illustrates the effect that the age of the driver had on the average actual gap.

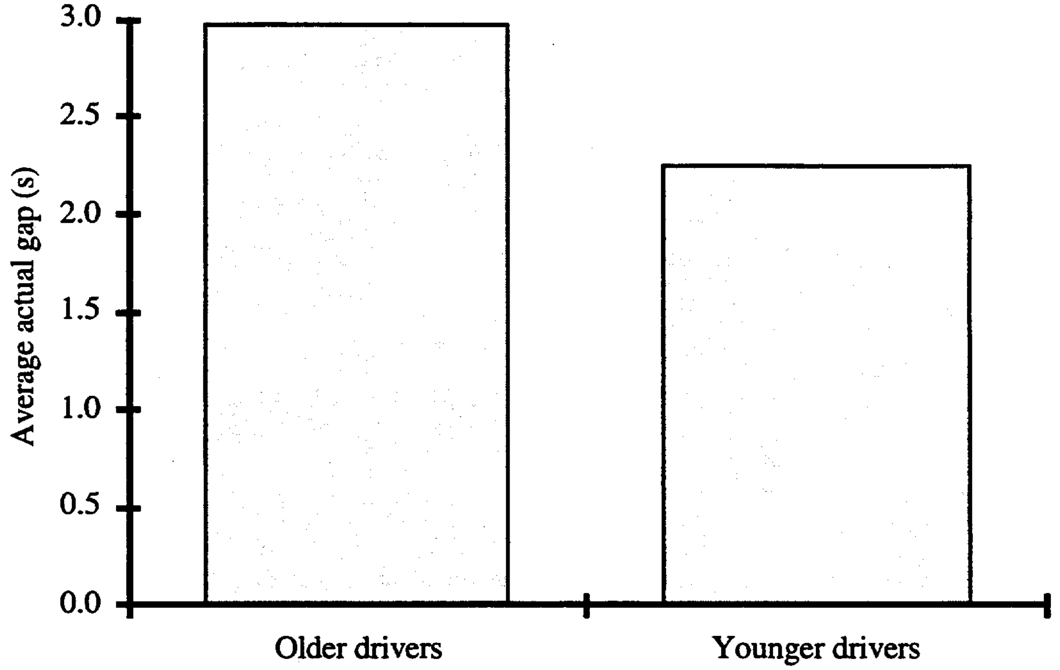

Figure 28. Average actual gap in seconds for older and younger drivers.

The figure shows that, like the minimum following distance, the average actual gap was considerably longer for older drivers than it was for younger drivers—the gaps were 3.0 s and 2.3 s, respectively.

Summary of the Effects of Driving While Using Only the CWS

The driving performance of the drivers in the control group was compared with that of the drivers in the experimental group while they were using only the CWS. The results were as follows:

- When the experimental-group drivers were using only the CWS, their steering instability was 0.24 m (0.79 ft), less than the 0.28-m (0.93-ft) steering instability of the control-group drivers. They also had more steering oscillations (18.0/min) than the controls (11.6/min). The experimental-group drivers had reduced their steering instability while increasing the number of steering oscillations. They were steering more precisely than the control-group drivers, by making more frequent steering correction movements of much smaller amplitude than those made by the control-group drivers.
- When the experimental-group drivers were using only the CWS, their average velocity was 2.54 km/h (1.16 mi) greater than the controls when the visibility was clear, 2.81 km/h (1.75 mi) greater than the controls when the visibility was 200 m (656 ft), and 4.75 km/h (2.95 mi) greater than the controls when the visibility was 100 m (328 ft).
- When the experimental-group drivers were using only the CWS, their velocity instability was 2.4 km/h (1.5 mi/h), less than the 4.9 km/h (3.0 mi/h) velocity instability of the control-group drivers. They also had many more velocity fluctuations (13.6/min) than the controls (only 2.9/min). The experimental-group drivers had reduced their velocity instability while increasing the number of velocity fluctuations. They were controlling the speed more precisely than the control-group drivers, by making more frequent speed corrections of much smaller amplitude than those made by the control-group drivers.
- When the minimum following distance and the average actual gap of the experimental-group drivers were compared with the minimum following distance and the average actual gap of the control-group drivers, no evidence was found to indicate that group had any effect on either measure.

DRIVING WHEN THE SSGCS AND CWS WERE DISENGAGED

So far the analysis has been concerned with how using one of the two intelligent vehicle systems affected driving performance. In this section, the analysis shifts focus in order to determine whether having used the SSGCS affected the driver's subsequent performance when both intelligent systems were disengaged. For this analysis, driving-performance data of the control-group drivers were compared with data obtained from the drivers in the experimental group, after the latter drivers had activated the SSGCS at least once, but when both the SSGCS and the CWS were currently disengaged.[7]

When either the SSGCS or the CWS was activated, there may have been a direct effect on driving performance. Here, when these systems were disengaged, the analysis explores whether the driver's subsequent performance had been affected by his/her prior use of the SSGCS. Driving-performance data obtained from the control-group drivers, and from the experimental-group drivers after they had used the SSGCS at least once but while both the SSGCS and CWS were disengaged, were compared using all the lane-keeping, speed-control, and following-distance measures listed in table 3. These comparisons were conducted using ANOVA's, with the results reported below.

Steering Instability When the SSGCS and CWS Were Disengaged

An ANOVA was used to determine the effect of prior use of the SSGCS on steering instability, with the results shown in table 16. The complete summary for this ANOVA is presented as table 54 in appendix 7.

Table 16. Summary showing only the statistically significant effects found by the ANOVA used to determine if steering instability was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group	0.0269
Group by age by visibility level	0.0111

As can be seen from table 16, group was the only variable that had a statistically significant main effect on steering instability. It was also involved in a significant three-way interaction with the age of the driver and the visibility level.

Interaction of Group, Age, and Visibility. The three-way interaction is depicted in figure 29.

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[7]Data obtained when both the SSGCS and the CWS were disengaged, but *before* the driver had activated the SSGCS at least once, were not included in this analysis.

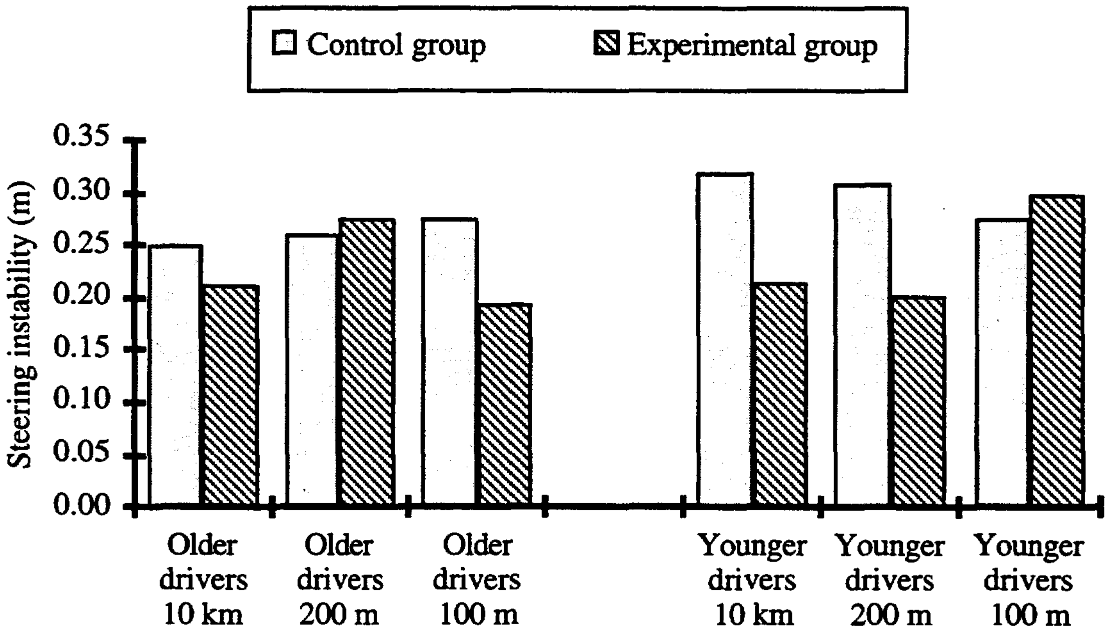

Figure 29. Steering instability in meters as a function of age and visibility for drivers in the experimental group (with the SSGCS and CWS disengaged) and in the control group.

Effect of Group. Inspection of figure 29 indicates that the effect of group on steering instability is not clear cut. There was more steering instability for the control-group drivers in four combinations of conditions—for the older drivers when the visibility was clear and when it was 100 m (328 ft), and for the younger drivers when the visibility was clear and when it was 200 m (656 ft). In contrast, there was less steering instability for the control-group drivers in the two remaining combinations of conditions—for the older drivers when the visibility was 200 m (656 ft), and for the younger drivers when the visibility was 100 m (328 ft). Because of the ambiguous nature of the relationship between group and steering instability, and in spite of the fact that there was a statistically significant effect of group, a figure showing steering instability as a function of group (averaged over the other variables) has not been included in this report.

Effects of Age and Visibility. The effects of age and visibility were at least as mixed as those of group. As figure 29 indicates, there was less steering instability for older drivers than there was for younger drivers in four out of six cases. And, as far as visibility is concerned, there was less instability when the visibility was clear for older control-group drivers, less instability when the visibility was 200 m (656 ft) for younger experimental-group drivers, and less instability when the visibility was 100 m (328 ft) for older experimental-group drivers and for younger control-group drivers.

Steering Oscillations When the SSGCS and CWS Were Disengaged

The effect of prior use of the SSGCS on the number of steering oscillations was explored using an ANOVA. The results of this procedure are shown in table 17. The complete summary for this ANOVA is presented as table 55 in appendix 7.

Table 17. Summary showing only the statistically significant effects found by the ANOVA used to determine if the number of steering oscillations was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group	0.0001
Visibility level	0.0001
Group by age	0.0072
Age by visibility level	0.0050
Group by age by visibility level	0.0046
Age by traffic density by visibility level	0.0393
Group by age by traffic density	0.0166

Table 17 shows that two variables, group and the visibility level, had statistically significant main effects on the number of steering oscillations. In addition, there were two significant two-way interactions and three significant three-way interactions. The three-way interactions are discussed first.

Interaction of Group, Age, and Visibility. The three-way interaction of group, the age of the driver, and visibility level is illustrated in figure 30.

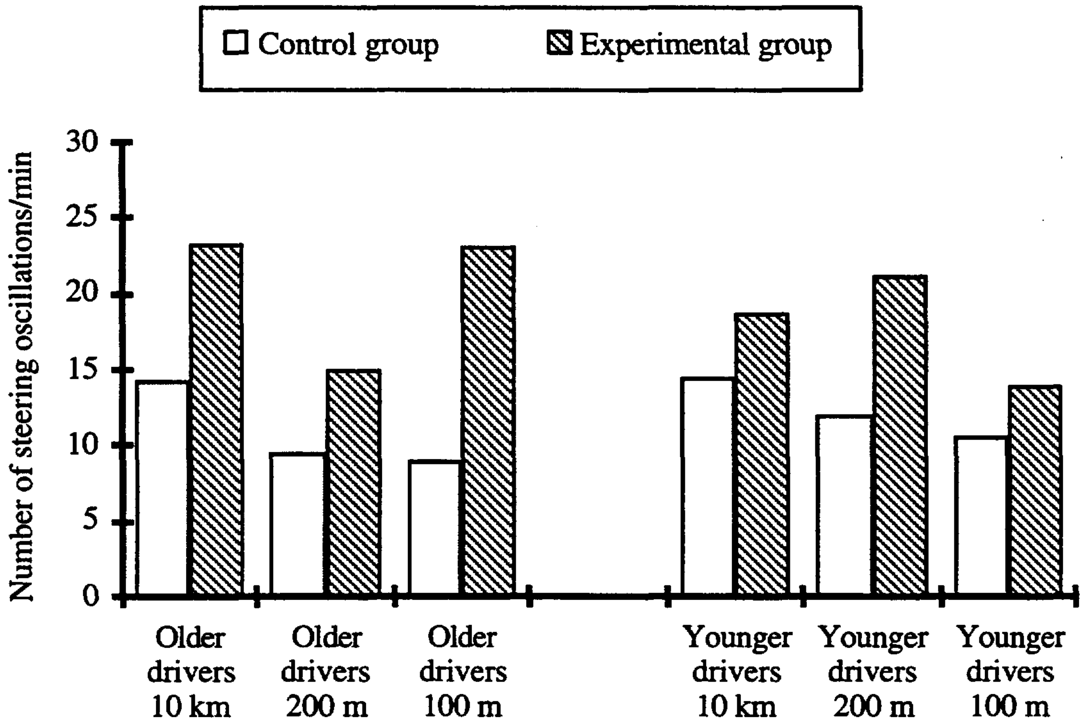

Figure 30. Number of steering oscillations/min as a function of age and visibility for drivers in the experimental group (with the SSGCS and CWS disengaged) and in the control group.

Effect of Group. The effect of group on the number of steering oscillations/min can be seen by comparing adjacent columns in figure 30; in all six cases, the number of steering oscillations was smaller for drivers in the control group than it was for drivers in the experimental group when the SSGCS and CWS were disengaged. The main effect of group is discussed in the subsection "Effect of Group" under the section on the "Interaction of Group, Age, and Traffic Density."

Effect of Visibility. The main effect of the visibility level on the number of velocity fluctuations is less clear, as figure 30 shows. For both older and younger control-group drivers, the number of steering oscillations decreased as the visibility level deteriorated. For older drivers in the experimental group, the largest number of oscillations also occurred when the visibility was clear, but the order for the two fog conditions was reversed compared with the control-group drivers. And for younger drivers in the experimental group, the smallest number of oscillations also occurred when the visibility was 100 m (328 ft), and the order for the two higher visibility-level conditions was reversed compared with the control-group drivers. The main effect of visibility is discussed in the section on the "Interaction of Age, Traffic Density, and Visibility."

Effect of the Age of the Driver. Figure 30 shows that there were fewer steering oscillations for older drivers in the control group than there were for younger controls. There were also fewer steering oscillations for older drivers in the experimental group in the 200-m (656-ft) visibility level than there were for the younger experimental-group drivers in the same visibility level. However, there were more steering oscillations for the older drivers in the experimental group in the clear- and 100-m (328-ft) visibility levels than there were for the younger experimental-group drivers in those two visibility levels.

Interaction of Age, Traffic Density, and Visibility. The three-way interaction among the age of the driver, the traffic density, and the visibility level is shown in figure 31.

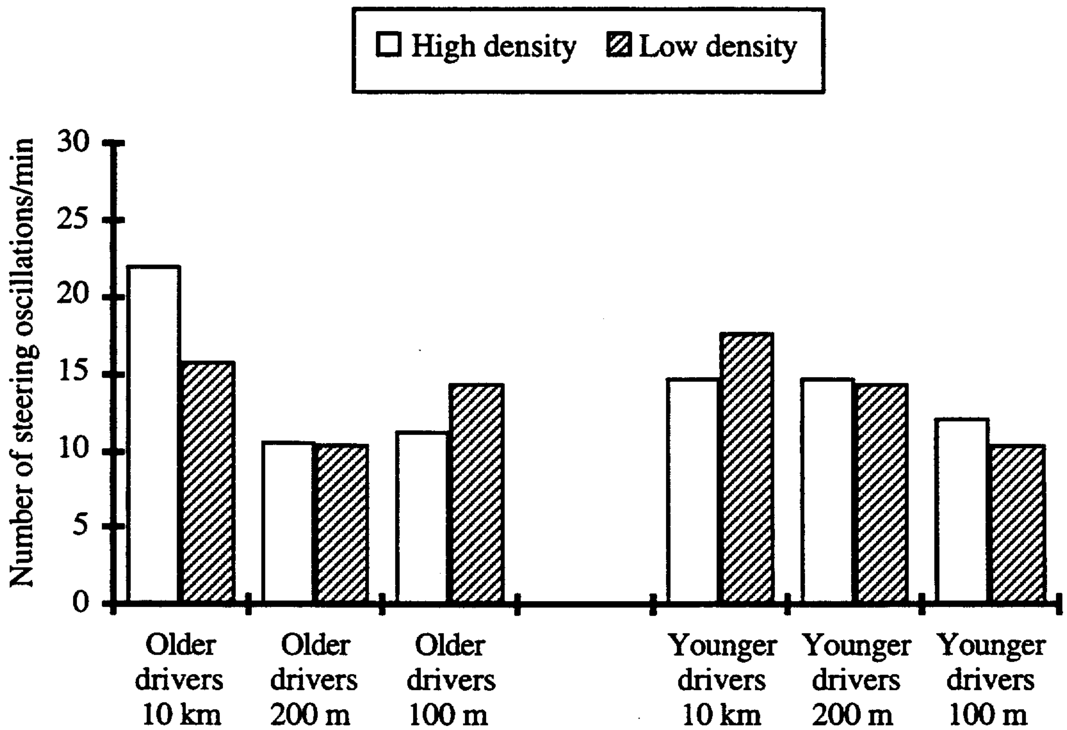

Figure 31. Number of steering oscillations/min as a function of age, visibility, and density.

Effect of Visibility. The main effect of the visibility level, already seen in the previous subsection dealing with the interaction among group, visibility, and age, can be seen again in figure 31. For older drivers in both high- and low-density traffic and younger drivers in low-density traffic, the number of steering oscillations was greatest when the visibility was clear. And for younger drivers in both the high- and low-density traffic, the number of steering oscillations was fewest when the visibility was 100 m (328 ft). And, as mentioned above, the main effect of visibility is discussed later.

Effect of the Age of the Driver. The effect of the age of the driver, already seen in the previous subsection dealing with the interaction among group, visibility, and age, can also be seen in figure 31. There were fewer steering oscillations for older drivers who drove in high-density traffic in the 200-m (656-ft) and 100-m (328-ft) fog, and who drove in low-density traffic in the clear and in the 200-m (656-ft) fog. And, there were more steering oscillations for older drivers who drove in high-density traffic in the clear, and who drove in low-density traffic in the 100-m (328-ft) fog.

Effect of Traffic Density. The effect of traffic density can be seen by comparing the adjacent columns in figure 31. There were more steering oscillations for the high-density traffic than for the low when older drivers drove in the clear and in 200-m (656-ft) fog, and when younger drivers drove in the 200-m (656-ft) and 100-m (328-ft) fog. In contrast, there were fewer steering oscillations for the high-density traffic than for the low when older drivers drove in 100-m (328-ft) fog, and when younger drivers drove in the clear.

<u>Interaction of Group, Age, and Traffic Density.</u> Figure 32 illustrates the third three-way interaction, among the age of the driver, the traffic density, and the visibility level.

Effect of Group. The effect of group on the number of steering oscillations/min is as clear in figure 32 as it was in figure 30 (where the three-way interaction among group, age, and visibility was shown): the number of steering oscillations was smaller for drivers in the control group than it was for drivers in the experimental group when the SSGCS and CWS were disengaged.

Effect of the Age of the Driver. As figure 32 shows, for three of the possible comparisons between older and younger drivers—those for both the experimental and control-group drivers driving in low-density traffic, and for the control-group drivers when they were driving in high-density traffic—there was a similar pattern for both age groups, with the number of steering oscillations for the older driver being slightly less than the number for the younger drivers. However, for the remaining comparison—that for the drivers in the experimental group driving with the SSGCS and CWS disengaged—there were significantly more steering oscillations for older drivers than there were for younger drivers.

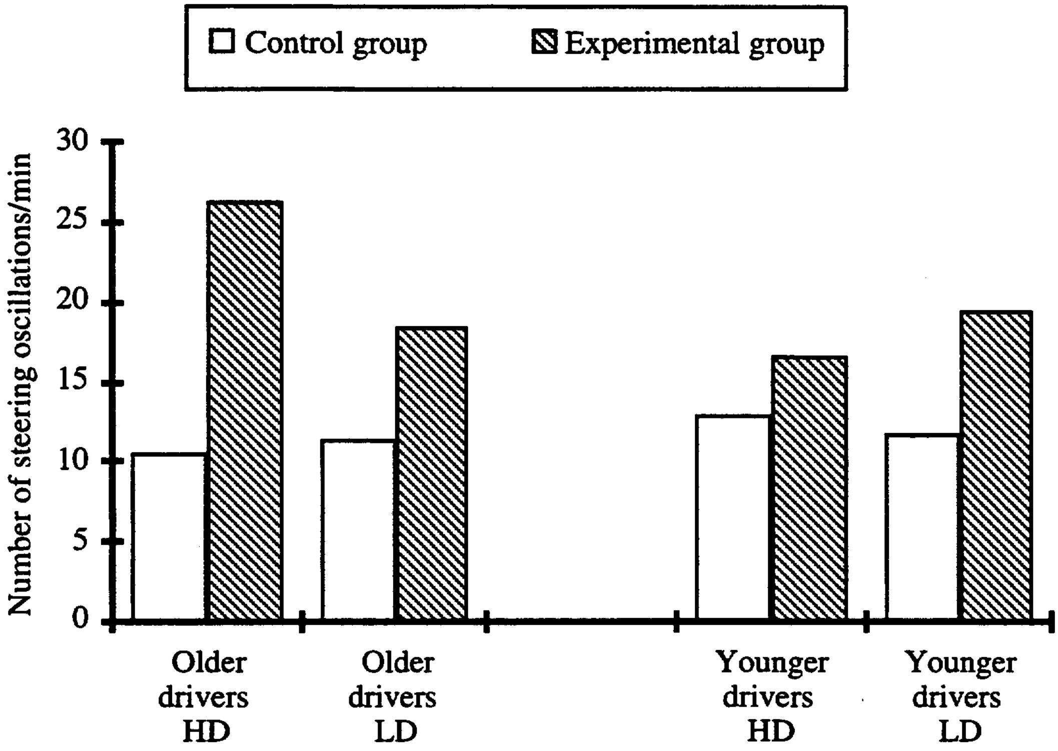

Figure 32. Number of steering oscillations/min as a function of age and density for drivers in the experimental group (with the SSGCS and CWS disengaged) and in the control group. [HD = high density, LD = low density.]

Effect of Traffic Density. Like figure 31, figure 32 indicates that the effect of density was mixed. The number of steering oscillations was higher when the density was 12.42 v/km/ln (20 v/mi/ln) than when it was 6.21 v/km/ln (10 v/mi/ln) for older drivers in the experimental group and younger drivers in the control group; in contrast, it was lower when the density was 12.42 v/km/ln (20 v/mi/ln) than when it was 6.21 v/km/ln (10 v/mi/ln) for older drivers in the control group and younger drivers in the experimental group

<u>Group.</u> The main effect of group on the number of steering oscillations, which could be seen in the two figures (30 and 32) showing the interactions involving group, is shown in figure 33. The number for the drivers in the control group was 11.6/min, which was significantly lower

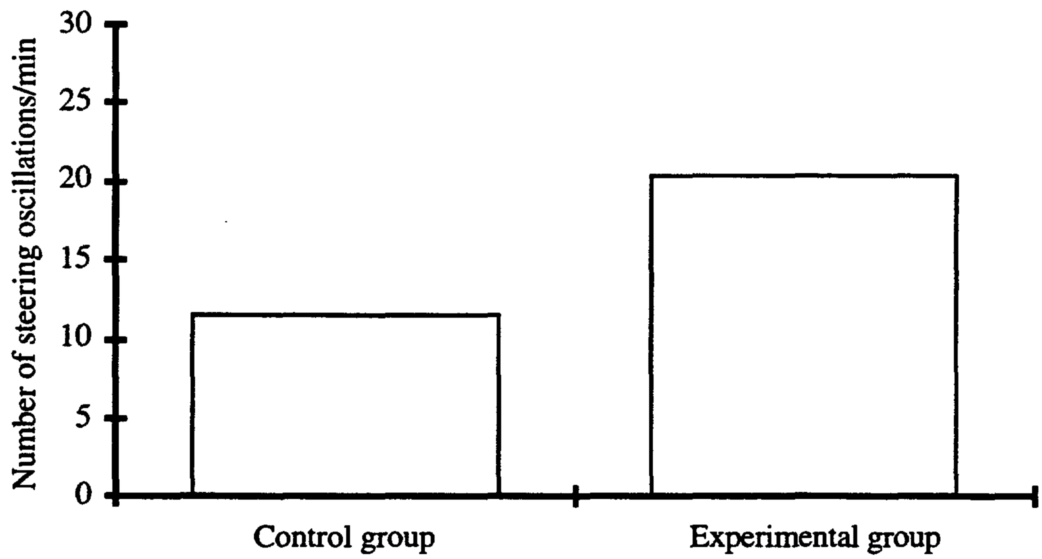

Figure 33. Number of steering oscillations/min for drivers in the experimental group (with the SSGCS and CWS disengaged) and in the control group.

than the number for the experimental-group drivers, who had 20.5 steering oscillations/min.

Visibility. The main effect of the level of visibility on the number of steering oscillations, discussed in connection with figures 30 and 31, is shown in figure 34.

Figure 34 shows that, on average, the number of steering oscillations decreased when the visibility level decreased. There were 18.0 oscillations/min when the visibility was clear; this dropped to 12.7/min when the visibility was 200 m (656 ft), and to 12.2/min when the visibility was 100 m (328 ft).

Average Velocity When the SSGCS and CWS Were Disengaged

An ANOVA was conducted in order to determine whether prior use of the SSGCS had an effect on the average velocity, with the results shown in table 18. The complete summary for this ANOVA is presented as table 56 in appendix 7.

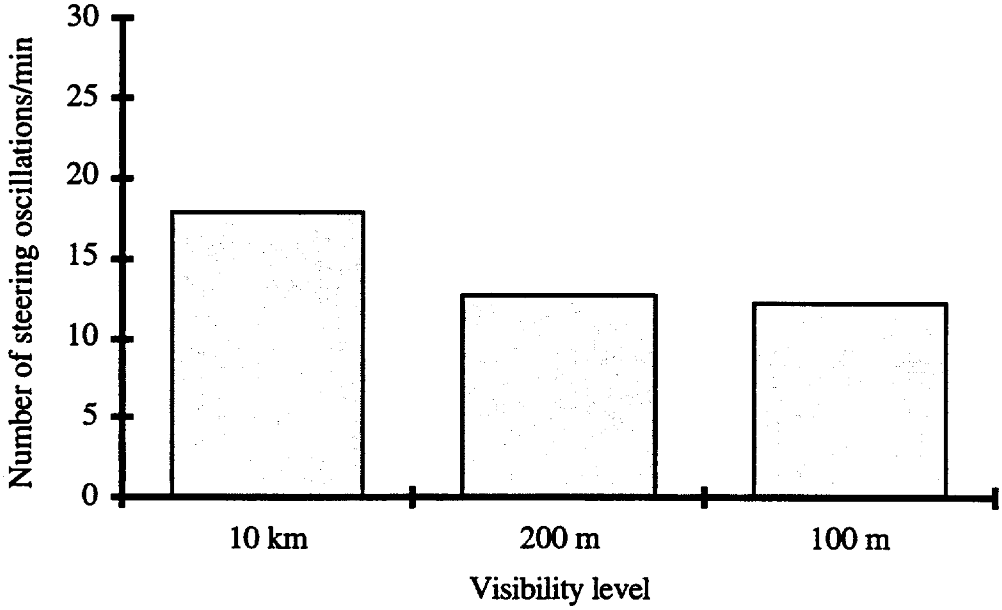

Figure 34. Number of steering oscillations/min as a function of the visibility level.

Table 18. Summary showing only the statistically significant effects found by the ANOVA used to determine if the average velocity was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age	0.0015
Visibility	0.0001
Group by traffic density by visibility	0.0362

Table 18 indicates that the age of the driver and the level of visibility had statistically significant effects on the average velocity. The visibility level was also involved in a three-way interaction with traffic density and the group.

Age of the Driver. The effect of the driver's age on the average velocity is shown in figure 35.

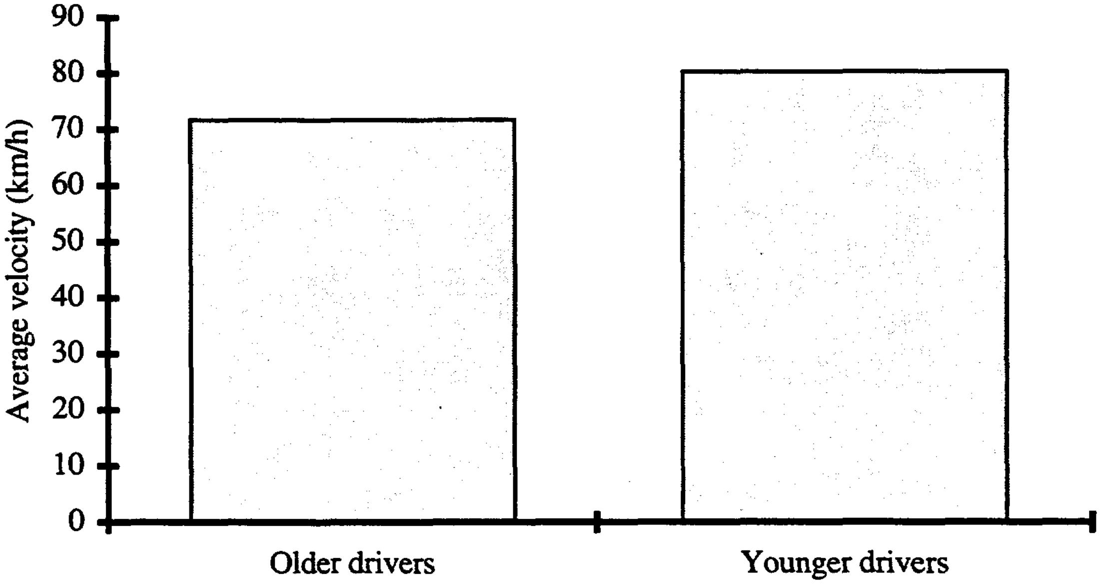

Figure 35. Average velocity as a function of age.

As figure 35 illustrates, younger drivers had an average velocity of 80.6 km/h (50.4 mi/h), greater than that of the older drivers, who had an average velocity of 72.0 km/h (44.7 mi/h).

Interaction of Group, Traffic Density, and Visibility. The three-way interaction among group, traffic density, and visibility level is shown in figure 36.

Effect of Visibility. The significant overall effect of visibility on the average velocity can be seen clearly in figure 36. In all four of the possible comparisons, the average velocity decreased as the visibility deteriorated. Specifically, the drivers in the control group, driving in either high- or low-density traffic, had a relatively large drop in velocity when the visibility dropped from 200 m (656 ft) to 100 m (328 ft); whereas, for drivers in the experimental group, those who drove in high-density traffic had a relatively large drop in velocity only when the visibility dropped from clear to 200 m (656 ft), while those who drove in low-density traffic had a consistent drop in velocity over all three visibility levels. The overall effect of visibility is discussed further below.

Effect of Group. The effect of the group to which the driver was assigned can be determined by comparing the adjacent pairs of columns in figure 36. In two cases, with high-density traffic in

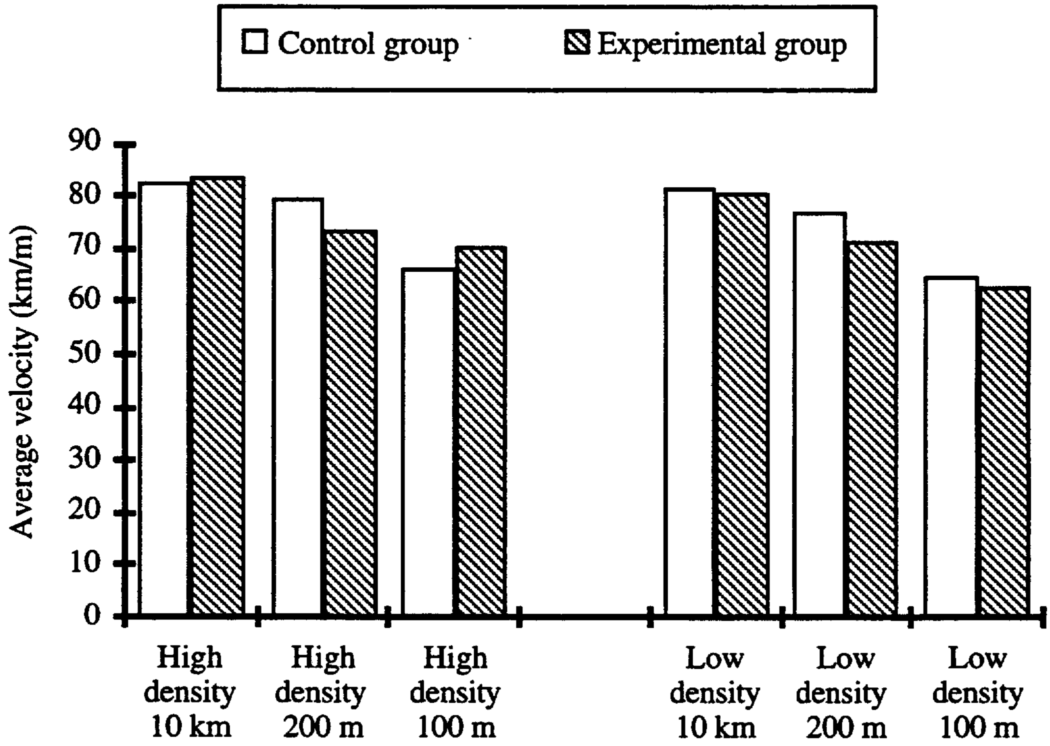

Figure 36. Average velocity as a function of density and visibility for drivers in the experimental group (when both the SSGCS and the CWS were disengaged) and in the control group.

clear or 100-m (328-ft) visibility, drivers in the experimental group have a higher velocity. In the remaining four cases, with high-density traffic in 200-m (656-ft) visibility, and with low-density traffic in all three visibility levels, the drivers in the experimental group have a lower velocity.

Effect of Traffic Density. When each of the set of six columns on the left side of figure 36 is compared with the equivalent column in the set of six columns to the right, it can be seen that, in every case, the average velocity is higher for the high-density condition. The effect is relatively small, with the exception of the combination of experimental group and 100-m (328-ft) visibility, where the average velocity was 7.3 km/h (4.6 mi/h) faster for the high density than for the low.

Visibility level. The overall effect of the level of visibility is shown in figure 37.

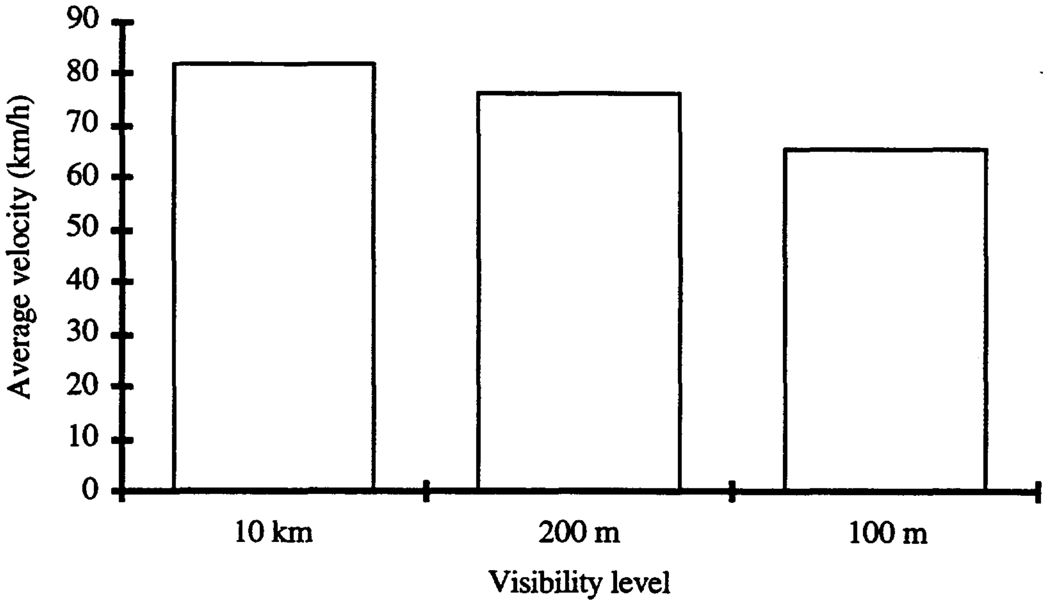

Figure 37. Average velocity as a function of visibility.

Figure 37 shows the overall effect of the level of visibility on the average velocity. As the visibility deteriorated, the average velocity dropped. When the visibility was clear, the average velocity was 82.3 km/h (51.1 mi/h). In the second section of the journey, the visibility dropped to 200 m (656 ft) and the velocity dropped to 76.8 km/h (47.7 mi/h). The latter velocity is 93.3 percent of that in the clear condition, which is almost identical to the 93.7 percent (calculated from Hawkins' observational data for this visibility) that was used to determine the speed of the other vehicles present on the expressway in this experiment.(16) In the third section of the journey, when the visibility deteriorated still further, to 100 m (328 ft), the average velocity dropped again, to 65.8 km/h (40.9 mi/h). The velocity in the third section was 79.9 percent of that in the clear visibility. Again, this is very similar to the 77.2 percent calculated from the data reported by Hawkins for this visibility.(16)

Velocity Instability When the SSGCS and CWS Were Disengaged

The results of the ANOVA conducted in order to determine whether prior use of the SSGCS had an effect on velocity instability are shown in table 19. The complete summary for this ANOVA is presented as table 57 in appendix 7.

Table 19. Summary showing only the statistically significant effects found by the ANOVA used to determine if velocity instability was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group	0.0001

<u>Group.</u> Table 19 indicates that the only variable to have an effect on velocity instability was the group to which the driver was assigned. The effect is shown in figure 38.

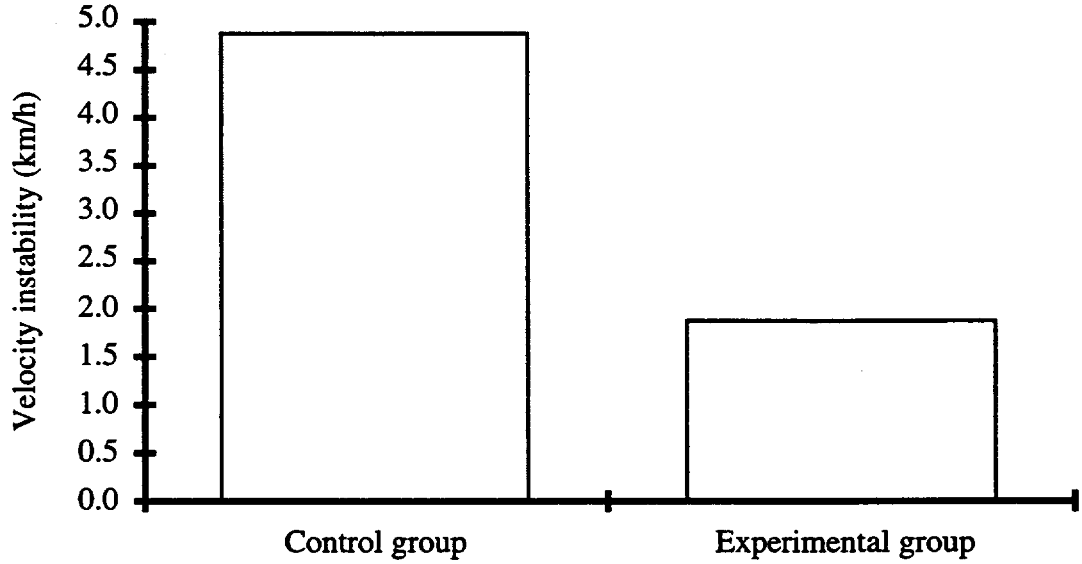

Figure 38. Velocity instability for drivers in the experimental group (when both the SSGCS and the CWS were disengaged) and in the control group.

As figure 38 shows, the velocity instability for the control-group drivers was more than double that of the drivers in the experimental group when both the SSGCS and the CWS systems were disengaged. The velocity instability was 4.9 km/h (3.0 mi/h) for the control-group drivers and 1.9 km/h (1.2 mi/h) for the experimental-group drivers.

Number of Velocity Fluctuations When the SSGCS and CWS Were Disengaged

The results of the ANOVA conducted to determine whether prior use of the SSGCS had an effect on the number of velocity fluctuations are shown in table 20. The complete summary for this ANOVA is presented as table 58 in appendix 7.

Table 20. Summary showing only the statistically significant effects found by the ANOVA used to determine if the number of velocity fluctuations was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Group	0.0001
Visibility level	0.0001
Age by visibility level	0.0046
Group by visibility level	0.0002
Traffic density by visibility level	0.0052
Group by age by visibility level	0.0041
Age by traffic density by visibility level	0.0001
Group by traffic density by visibility level	0.0146
Group by age by traffic density by visibility level	0.0001

Table 20 indicates that two of the independent variables had statistically significant effects on the number of velocity fluctuations: group and the level of visibility. In addition, there were three significant two-way interactions, three significant three-way interactions, and one significant four-way interaction. The four-way interaction subsumes all the other effects, and usually would be discussed first. However, in this case, in some cells the sample was too small for this to be valid. Instead, the three three-way interactions are discussed first, followed by comments on the two main effects.

Interaction of Group, Age, and Visibility. The first of the three-way interactions is illustrated in figure 39.

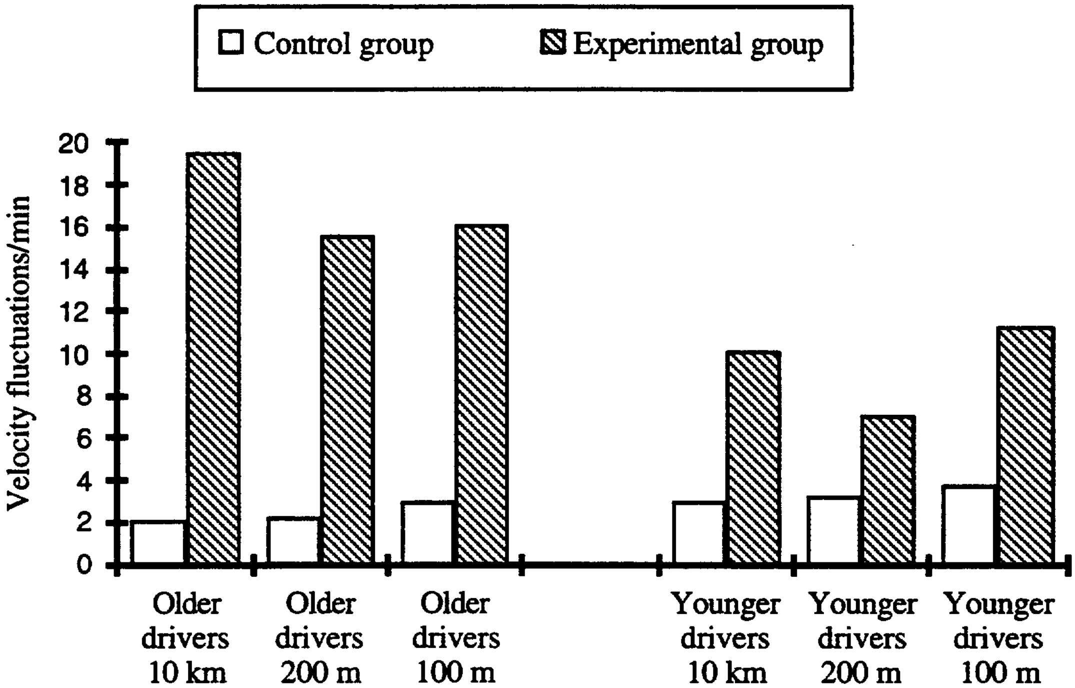

Figure 39. Number of velocity fluctuations/min as a function of age and visibility level for drivers in the experimental group (when both the SSGCS and the CWS were disengaged) and in the control group.

Effect of Group. It is very clear from figure 39 that, for all six combinations of age and visibility, the control-group drivers had far fewer velocity fluctuations than the experimental-group drivers when both the SSGCS and the CWS were disengaged. The Group main effect is discussed in the section below on "Group."

Effect of Visibility. There was a significant main effect of visibility; however, inspection of figure 39 does not clarify its effect. For the older and younger control-group drivers, the number of velocity fluctuations increased slightly as the visibility level dropped. However, for drivers in the experimental group there were many more fluctuations, with the smallest number occurring when the drivers were driving in the 200-m (656-ft) fog.

Effect of Age. Figure 39 shows that, when the control group is considered, the number of velocity fluctuations was a little higher for younger drivers than it was for older drivers. In contrast, for the experimental group, an opposing and stronger effect was found—the number of velocity fluctuations was considerably higher for the older drivers than it was for the younger.

Interaction of Age, Traffic Density, and Visibility. The second of the significant three-way interactions obtained from the analysis of the number of velocity fluctuations is explored in figure 40.

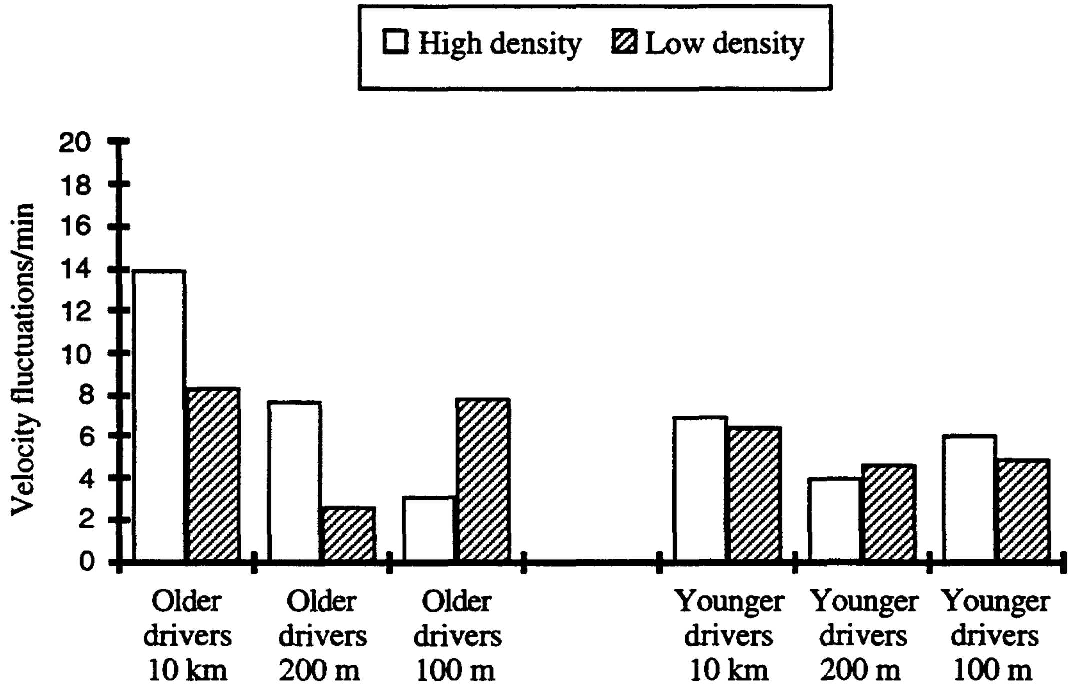

Figure 40. Number of velocity fluctuations/min as a function of age, visibility, and traffic density.

Effect of Visibility. Earlier, figure 39 did not give a consistent picture of the effect of visibility on the number of velocity fluctuations. However, when its interaction with traffic density and the age of the driver is explored in figure 40, a more consistent view of the relationship with the number of velocity fluctuations seems to emerge. In all cases, the most velocity fluctuations occurred when the visibility was 10 km (6.21 mi). In addition, the fewest fluctuations occurred when the visibility was 200 m (656 ft) in three cases out of four. The exception occurred when the older drivers drove in high-density traffic—then the fewest fluctuations occurred when the visibility was 100 m (328 ft).

Effect of Age. In figure 40, the effect of the driver's age is mixed, as it was in figure 39. Here, there were more fluctuations for older drivers when the visibility was clear; for older drivers in the higher traffic density when the visibility was 200 m (656 ft); and for older drivers in the lower traffic density when the visibility was 100 m (328 ft). And, there were more fluctuations for younger drivers in the higher traffic density when the visibility was 100 m (328 ft); and for younger drivers in the lower traffic density when the visibility was 200 m (656 ft).

Effect of Traffic Density. Figure 40 shows that the effect of traffic density on the number of velocity fluctuations was also mixed. There were more fluctuations associated with the 12.42-v/km/ln (20-v/mi/ln) density for older drivers when they drove in the clear and with 200-m (656-ft) visibility, and for younger drivers when they drove in the clear and with 100-m (328-ft) visibility. In contrast, there were more fluctuations associated with the 6.21-v/km/ln (10-v/mi/ln) density for older drivers when they drove with 100-m (328-ft) visibility, and for younger drivers when they drove with 200-m (656-ft) visibility.

Interaction of Group, Traffic Density, and Visibility. The third significant three-way interaction that was obtained when the number of velocity fluctuations was analyzed is explored in figure 41.

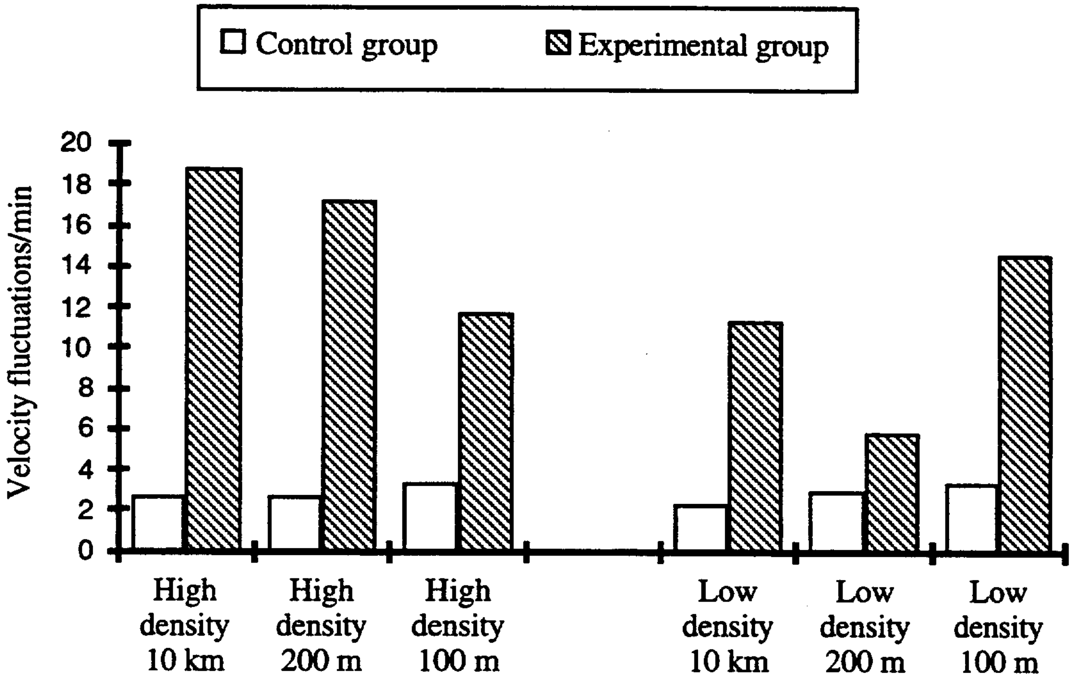

Figure 41. Number of velocity fluctuations/min as a function of density and visibility level for drivers in the experimental group (when both the SSGCS and the CWS were disengaged) and in the control group.

Effect of Group. Figure 41 shows that the control-group drivers had far fewer velocity fluctuations than the experimental-group drivers when both the SSGCS and the CWS were disengaged. The effect of group is discussed again later.

Effect of Visibility. Figure 41—like figure 39, but unlike figure 40—does not clarify the effect of visibility on the number of velocity fluctuations. In this figure, there were three cases where the most velocity fluctuations occurred with the 100-m (328-ft) visibility, and three where the fewest fluctuations occurred for the 200-m (65-ft) visibility, quite unlike the picture that emerged from figure 40. Because of the overall lack of consistency in depicting the relationship between the level of visibility and the number of velocity fluctuations, the overall effect of visibility is not discussed further in this report.

Effect of Traffic Density. Like figure 40, figure 41 shows that the effect of traffic density was mixed. There were more fluctuations associated with the 12.42-v/km/ln (20-v/mi/ln) density for both the experimental- and control-group drivers when they drove in the clear; for drivers in the experimental group when they drove with the 200-m (656-ft) visibility; and for drivers in the control group when they drove with the 100-m (328-ft) visibility. In contrast, there were more fluctuations associated with the 6.21-v/km/ln (10-v/mi/ln) density for drivers in the control group when they drove with the 200-m (656-ft) visibility; and for drivers in the experimental group when they drove with the 100-m (328-ft) visibility.

Group. As shown in figures 39 and 41, the group to which the driver was assigned had a clear effect on the number of velocity fluctuations. This effect is illustrated in figure 42.

Figure 42 shows that, when they drove with both the SSGCS and the CWS disengaged, drivers in the experimental group had four times as many velocity fluctuations as drivers in the control group. They had 13.8 and 2.9 fluctuations/min, respectively.

Minimum Following Distance When the SSGCS and CWS Were Disengaged

Up to this point, minimum following distance has been measured in two different ways for drivers in the experimental group. First, for the experimental-group drivers who were using the SSGCS, the measure was the shortest gap setting selected by these drivers. Second, for the experimental-group drivers who were using the CWS alone, the minimum following distance was measured in meters (and feet). The second way of measuring minimum following distance

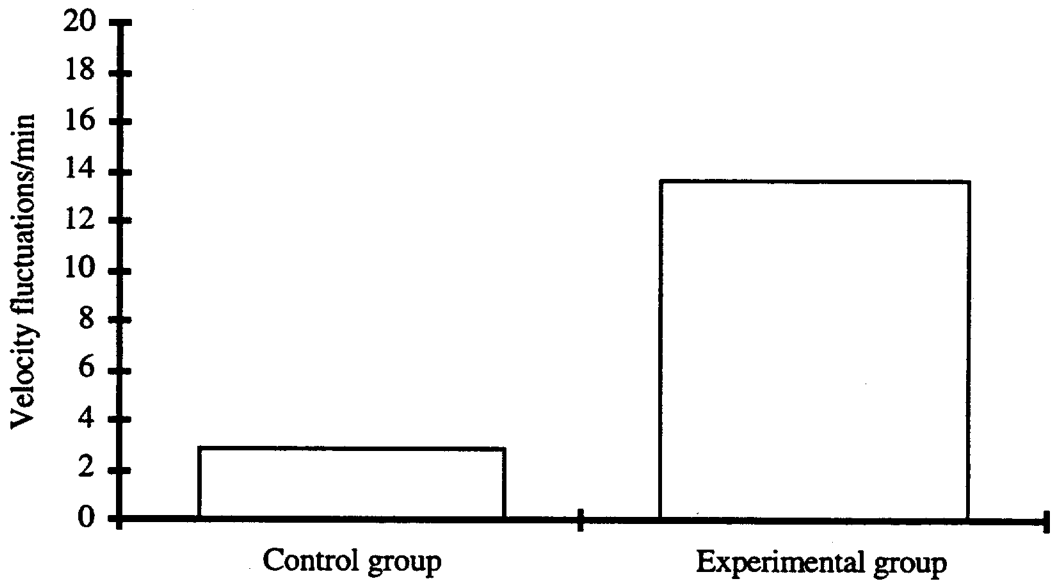

Figure 42. Number of velocity fluctuations/min for drivers in the experimental group (when both the SSGCS and the CWS were disengaged) and in the control group.

was used again for the analysis of the experimental-group drivers when the SSGCS and CWS were disengaged.

An ANOVA was conducted in order to determine whether prior use of the SSGCS had an effect on the minimum following distance. Table 21 shows the statistically significant main effects and interactions found in this analysis. The complete summary for this ANOVA is presented as table 59 in appendix 7.

Table 21. Summary showing only the statistically significant effects found by the ANOVA used to determine whether the minimum following distance was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age (A)	0.0227
Visibility level (V)	0.0081
A x V	0.0169

Table 21 indicates that the age of the driver and the visibility level both had a statistically significant effect on minimum following distance. In addition, these variables were also involved in a two-way interaction. It should be noted that there was no evidence to show that the minimum following distance was affected by whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or in the control group.

<u>Interaction of Age and Visibility.</u> The two-way interaction is illustrated in figure 43.

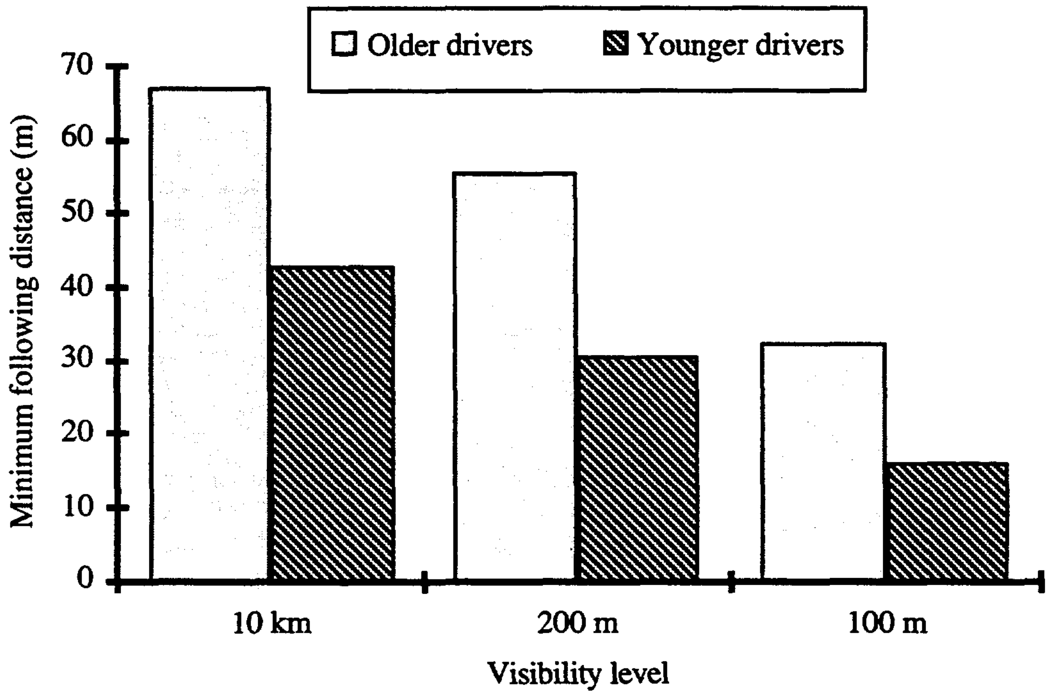

Figure 43. Minimum following distance in meters as a function of the visibility level for both older and younger drivers.

Figure 43 clearly reveals the significant main effects of age and visibility level, and both are discussed further in the next two subsections.

The interaction between the two variables occurred because the minimum following distance was approximately 24 m (79 ft) greater for older drivers than younger drivers when the drivers of both ages drove in the clear and in 200-m (656-ft) fog, but only 16 m (52 ft) greater when they both drove in 100-m (328-ft) fog.

Age of the Driver. Figure 44 shows the effect of the driver's age on the minimum following distance. The minimum following distance was considerably longer for older drivers than it was for younger drivers. On average, the distances were 54.5 m (178.6 ft) and 32.0 m (103.3 ft), respectively.

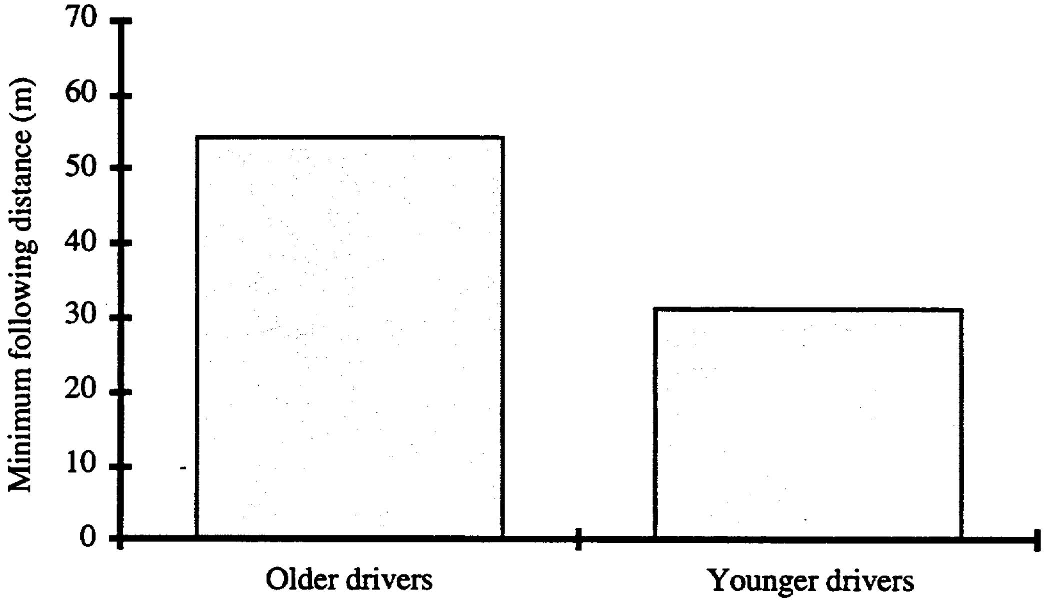

Figure 44. Minimum following distance in meters as a function of age.

Visibility. Figure 45 shows the effect of visibility level on the minimum following distance.

Figure 45 shows that the minimum following distance decreased steadily with visibility. The average minimum following distance dropped from 54.2 m (177.6 ft) when drivers drove with clear visibility, to 41.6 m (136.3 ft) when they drove in 200-m (656-ft) fog, and then to 23.2 m (75.9 ft) when the visibility dropped to 100 m (328 ft).

Average Actual Gap When the SSGCS and CWS Were Disengaged

As mentioned earlier, the average actual gap is a second measure of following distance. The results of the ANOVA that was used to compare the average actual gap between the driver's car and the vehicle ahead for control-group drivers and for experimental-group drivers when both

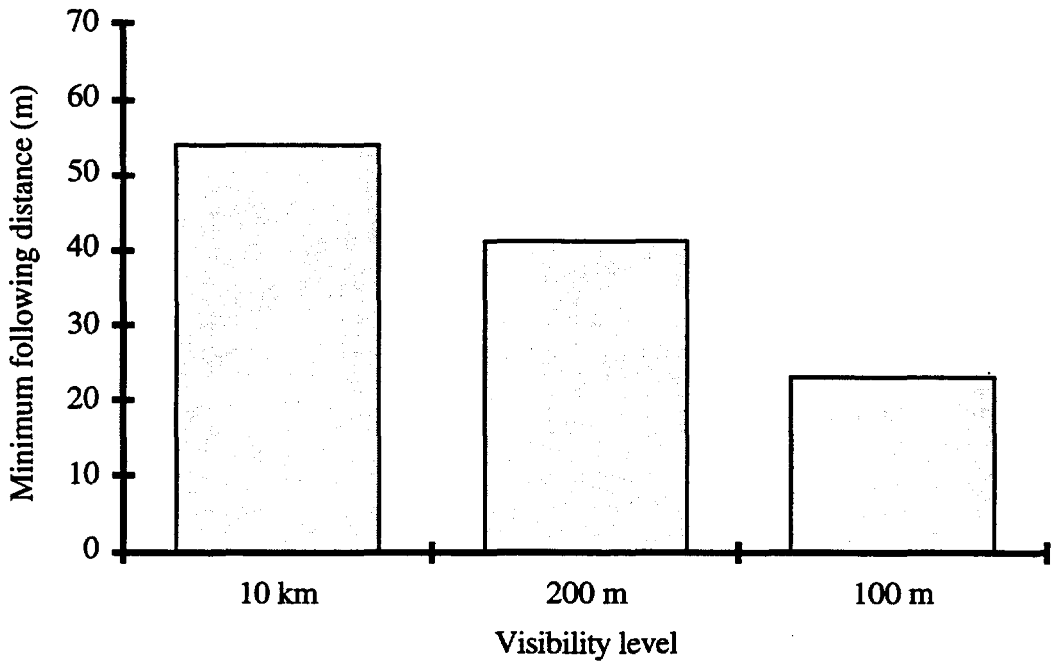

Figure 45. Minimum following distance as a function of visibility.

the SSGCS and the CWS were disengaged are shown in table 22. The complete summary for this ANOVA is presented as table 60 in appendix 7.

Table 22. Summary showing only the statistically significant effects found by the ANOVA used to determine if the average actual gap was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or in the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	*p* Value
Age (A)	0.0003
Visibility level (V)	0.0030
A x V	0.0491
Group by visibility level (G x V)	0.0182
G x A x V	0.0074

Table 22 shows that two variables had statistically significant effects on the average actual gap; they were the age of the driver and the level of visibility. There were also two two-way interactions and one three-way interaction involving age, visibility, and group. The three-way interaction is discussed first, followed by a discussion of the main effects.

Interaction of Group, Age, and Visibility. The three-way interaction of group, the age of the driver, and the visibility level is examined in figure 46.

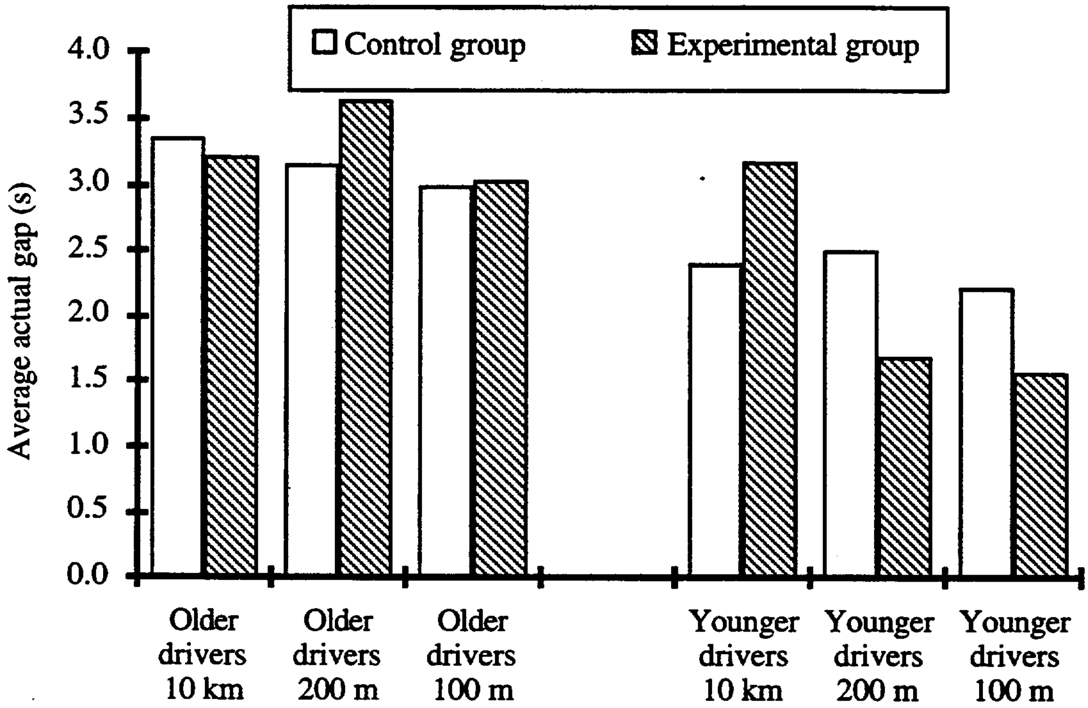

Figure 46. Average actual gap in seconds as a function of age and visibility for drivers in the experimental group (when both the SSGCS and the CWS were disengaged) and in the control group.

Effect of Group. As figure 46 shows, the effects of group are mixed. The older drivers in the control group had a larger average actual gap than the older drivers in the experimental group when the visibility was clear, and the younger drivers in the control group had a larger average actual gap than the younger drivers in the experimental group when the visibility was 200 m (656 ft) and 100 m (328 ft). In contrast, the older drivers in the experimental group had a larger average actual gap than the older drivers in the control group when the visibility was 200 m (656 ft) and 100 m (328 ft), and the younger drivers in the experimental group had a larger average actual gap than the younger drivers in the control group when the visibility was clear.

Effect of Age. In figure 46, for all six combinations of group and visibility, the older drivers had a larger average actual gap than the younger drivers. The age main effect is discussed in the section below on "Age of the Driver."

Effect of Visibility. In figure 46, for all four combinations of group and age, the average actual gap was shortest when the visibility was 100 m (328 ft). For the older control-group drivers and the younger experimental-group drivers, the average actual gap was longest when the visibility was clear; for the older experimental-group drivers and the younger control-group drivers, the average actual gap was longest when the visibility was 200 m (656 ft).

Age of the Driver. Figure 47 illustrates the effect that the age of the driver had on the average actual gap.

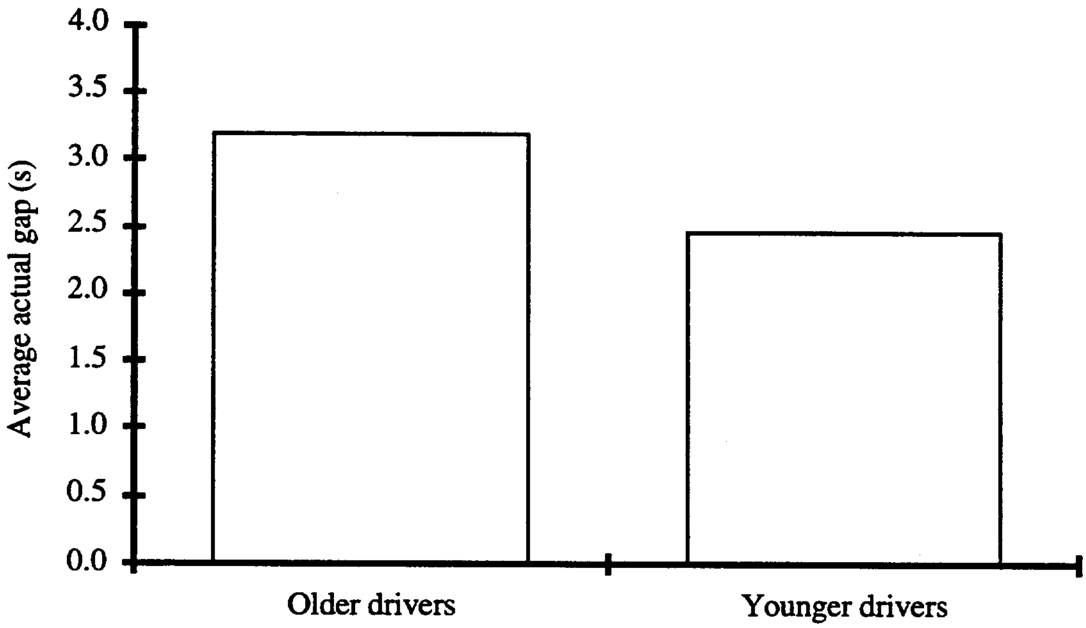

Figure 47. Average actual gap in seconds as a function of the driver's age.

As figure 47 shows, the average actual gap was longer for older drivers than it was for younger drivers. The gaps were 3.2 s and 2.5 s, respectively.

Visibility. Figure 48 illustrates the effect that the visibility level had on the average actual gap.

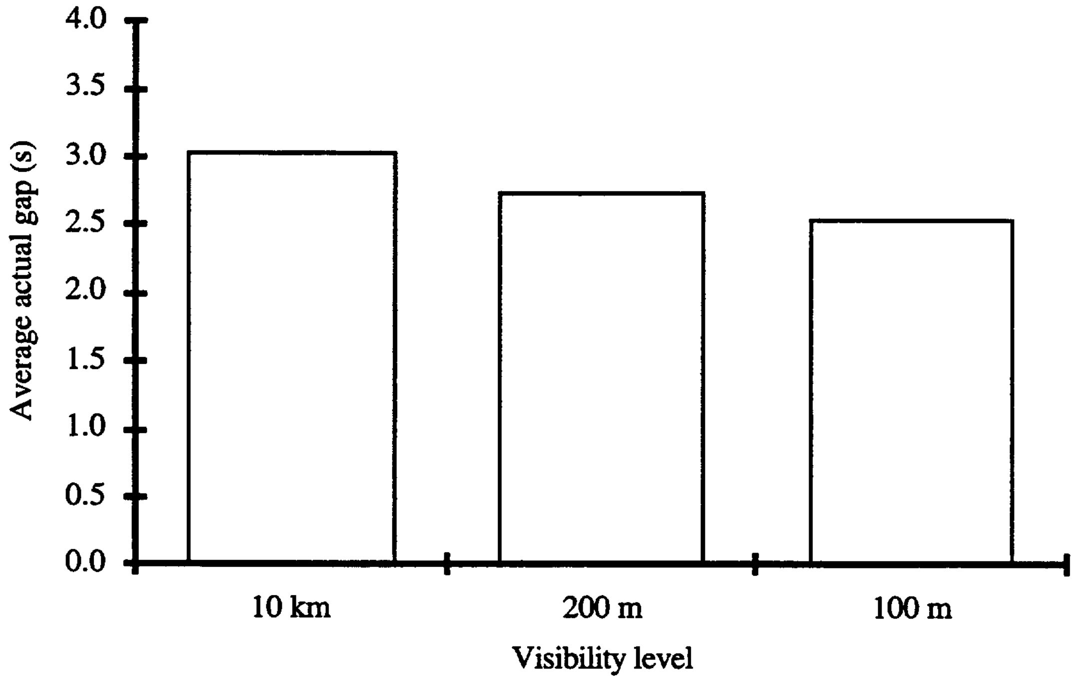

Figure 48. Average actual gap in seconds as a function of visibility.

Figure 48 shows that the average actual gap decreased with visibility. As the visibility dropped from 10 km (6.21 mi) to 200 m (656 ft) and then 100 m (328 ft), the average actual gap decreased from 3.05 s to 2.75 s and then to 2.55 s.

Summary of the Effects of Driving When the SSGCS and CWS Were Disengaged

The driving performance of drivers in the control group was compared with that of drivers in the experimental group, after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were currently disengaged. The results were as follows:

- When the steering instability of drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—was compared with that of drivers in the control group, the results were mixed. There was more steering instability for the experimental-group drivers than for the controls in two combinations of conditions—for older drivers when the visibility was 200 m (656 ft), and for younger drivers when the visibility was 100 m (328 ft). In contrast, there was less steering instability for the experimental-group drivers than for the controls in four combinations of conditions: for older drivers when the visibility was clear and when it was 100 m (328 ft), and for younger drivers when the visibility was clear and when it was 200 m (656 ft).

- When the number of steering oscillations for drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—was compared with the number for drivers in the control group, drivers in the experimental group were found to have had more steering oscillations (20.5/min) than the drivers in the control group (11.6/min).
- When the average velocity of drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—was compared with that of drivers in the control group, the results were mixed. The drivers in the experimental group had a higher velocity than the drivers in the control group in two cases: with high-density traffic in clear or 100-m (328-ft) visibility. And, drivers in the experimental group had a lower average velocity than drivers in the control group in four cases: with high-density traffic in 200-m (656-ft) visibility and with low-density traffic in all three visibility levels.
- The velocity instability and the number of velocity fluctuations of drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—were compared with those of drivers in the control group. The velocity instability of the experimental-group drivers was 1.9 km/h (1.2 mi/h), less than the 4.9 km/h (3.0 mi/h) velocity instability of the control-group drivers. The experimental-group drivers also had many more velocity fluctuations (13.8/min) than the controls (only 2.9/min). The experimental-group drivers reduced their velocity instability while increasing the number of velocity fluctuations. They were controlling the speed more precisely than the control-group drivers, by making more frequent speed corrections of much smaller amplitude than those made by the control-group drivers.
- The minimum following distance of drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—was compared with that of drivers in the control group. There was no evidence that there was any difference in the minimum following distance of the two groups.
- When the average actual gap of drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—was compared with that of drivers in the control group, the results were mixed. The older drivers in the experimental group had a larger average actual gap

than the older drivers in the control group when the visibility was 200 m (656 ft) and 100 m (328 ft), and the younger drivers in the experimental group had a larger average actual gap than the younger drivers in the control group when the visibility was clear. In contrast, older drivers in the experimental group had a smaller average actual gap than older drivers in the control group when the visibility was clear, and younger drivers in the experimental group had a smaller average actual gap than younger drivers in the control group when the visibility was 200 m (656 ft) and 100 m (328 ft).

THE LANE-CHANGING AND INCURSION BEHAVIOR OF DRIVERS WITH INTELLIGENT VEHICLE SYSTEMS

In this analysis section, the analysis of the five lane-change measures and the two incursion measures is reported. These data were partitioned only by visibility level. The lane-change and incursion data could be collected from the experimental-group drivers either when the CWS alone was activated, or when neither the SSGCS nor the CWS were activated. [It is to be remembered that the SSGCS automatically kept the vehicle in its lane. If the driver wanted to change lanes, he/she had to deactivate the SSGCS; one way to do this was to turn the steering wheel. Thus, a lane change or attempted lane change (an incursion) could occur only if the SSGCS was deactivated.]

The analysis of the SSGCS usage measure is also reported in this section of the analysis.

Number of Lane Changes

In this experiment, lane changing was completely under the control of the driver. Each driver chose the lane in which he/she was traveling at all times throughout the 35-min journey, and decided if, and when, he/she would move from one lane to another on the three-lane expressway.

Some drivers changed lanes quite frequently; others chose not to change lanes for long periods of time. Some drivers traveled in the same lane throughout complete segments of the journey; in such cases, there were no lane changes and there was no lane-changing behavior that could be associated with the visibility level in that segment.

A total of 308 lane changes was made at some time during their journey by the 32 drivers who were in the experimental group, while a total of 140 lane changes were made by the 20 drivers in the control group. Table 23 shows the average number of lane changes that were made during the journey by both older and younger drivers in each visibility level.

Table 23. Average number of lane changes (rounded to one decimal place) for younger and older drivers in the control and experimental groups for all visibility levels.

	Control Group		Experimental Group	
Visibility Level	Age 25-34	Age ≥65	Age 25-34	Age ≥65
10 km (6.2 mi)	3.4	2.0	2.6	1.3
200 m (656 ft)	3.4	0.5	4.8	1.6
100 m (328 ft)	3.2	1.5	7.0	2.0

To determine whether there were any dependencies in the lane-change data, they were regrouped into two 2 by 2 contingency tables for chi-squared analyses. Since the averages were too small to allow that statistic to be run, the total numbers of lane changes were used instead. Tables 24 and 25 show the rearranged data. For group by visibility level (table 24), the chi-squared test on the data was significant ($\chi^2[2] = 17.4$; $p < 0.001$). Thus, group and visibility level were related

Table 24. Total number of lane changes for each group by visibility-level combination.

Visibility Level	Control Group	Experimental Group
10 km (6.2 mi)	54	62
200 m (656 ft)	39	102
100 m (328 ft)	47	144

Table 25. Total number of lane changes for each age by visibility-level combination.

Visibility Level	Age 25-34	Age ≥65
10 km (6.2 mi)	76	40
200 m (656 ft)	111	30
100 m (328 ft)	144	47

to each other. Based on the averages (shown in table 26), it appears that, whereas visibility level had little effect on the control-group drivers, there was an increase in the average number of lane changes for the experimental-group drivers as visibility decreased.

Table 26. Average number of lane changes (rounded to one decimal place) for each group by visibility-level combination.

Visibility Level	Control Group	Experimental Group
10 km (6.2 mi)	2.7	1.9
200 m (656 ft)	2.0	3.2
100 m (328 ft)	2.4	4.5

For age by visibility level (table 25), there was also a significant interaction ($\chi^2[2] = 6.1$; $p < 0.05$); the average numbers of lane changes are shown in table 27. Based on the averages, it appears that the older drivers did not modify their lane change behavior as a function of visibility level, whereas the younger drivers made more lane changes on average as the visibility level decreased.

Table 27. Average number of lane changes (rounded to one decimal place) for each age by visibility-level combination.

Visibility Level	Age 25-34	Age ≥65
10 km (6.2 mi)	2.9	1.5
200 m (656 ft)	4.3	1.2
100 m (328 ft)	5.5	1.8

Percentage of Time Spent in the Left, Center, and Right Lanes

During each visibility period, the drivers could drive in the left, center, and right lanes of the expressway. The total amount of time that drivers spent in each of the lanes was recorded. Then, these totals were converted into percentages.

Figures 49 and 50 show the percentage of time spent in the left, center, and right lanes for each of the three visibility conditions by drivers in the experimental and control groups, respectively.

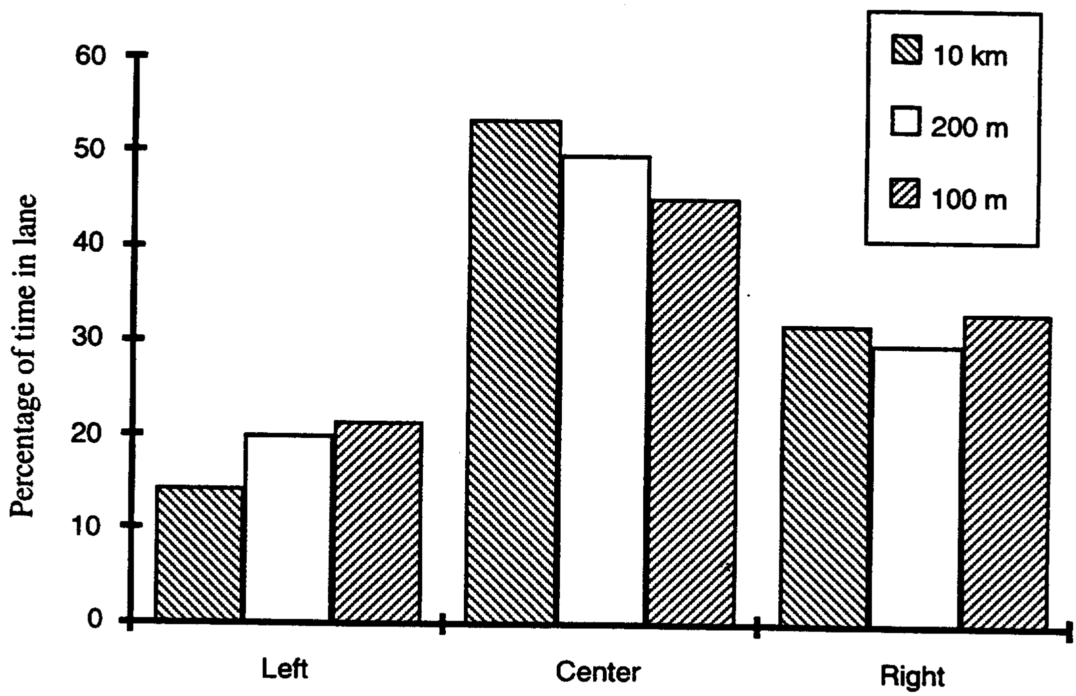

Figure 49. Percentage of time the control-group drivers were in the left, center, and right lane as a function of visibility.

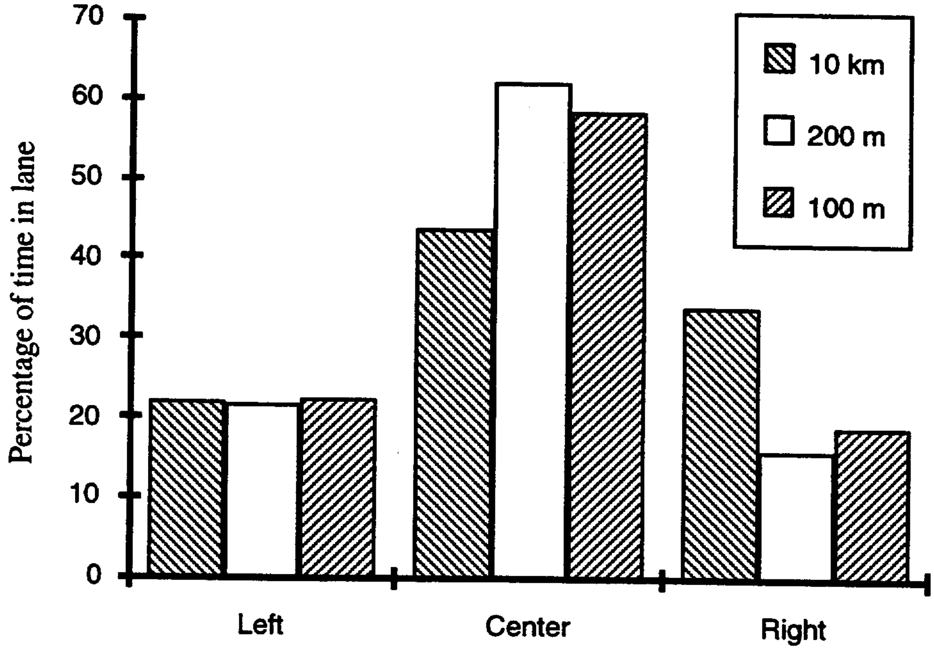

Figure 50. Percentage of time the experimental-group drivers were in the left, center, and right lane as a function of visibility.

Figure 49 shows that, for drivers in the control group, as the visibility decreased from clear to 100 m (328 ft), the amount of time spent in the left lane increased, the amount of time spent in the center lane decreased, and the amount of time spent in the right lane remained relatively unchanged.

Figure 50 shows a different pattern for the drivers in the experimental group. For them, as the visibility decreased from clear to 100 m (328 ft), the amount of time spent in the left lane remained constant, the amount of time spent in the center lane increased, and the amount of time spent in the right lane decreased.

Size of Gap Accepted in Lane Changes

In addition to recording the number of lane changes, the size of the gap that the driver moved into was determined for each lane change that occurred. For each lane change, the size of the gap was the distance between the back bumper of the vehicle ahead and the front bumper of the vehicle behind in the adjacent lane, at the time that the first wheel of the driver's car crossed the white line to enter the adjacent lane.

No statistical analyses were done on these data. When the visibility was 10 km (6.2 mi) and 200 m (656 ft), lane-change gaps longer than 350 m (1148 ft) were omitted; when the visibility was 100 m (328 ft), lane-change gaps longer than 200 m (656 ft) were omitted. For the remaining gaps for each group at each visibility level, the number of lane changes in each 25-m (82-ft) range was divided by the total number of lane changes examined to get the frequency within that range. Then, cumulative frequencies were determined across the entire range of gaps that were plotted. The cumulative frequencies of gap sizes accepted in lane changes (subject to the constraints indicated above) are shown in figure 51 for the three visibility levels.

- At each visibility level, the shapes of the plots for the experimental and control groups are very similar, indicating that their behavior did not differ substantially from each other at any given visibility level. (Although it appears that there is a tendency toward longer gaps for the experimental group than for the control group at 100-m [328-ft] visibility, the lack of statistical analysis makes it impossible to tell whether there is a real difference.)

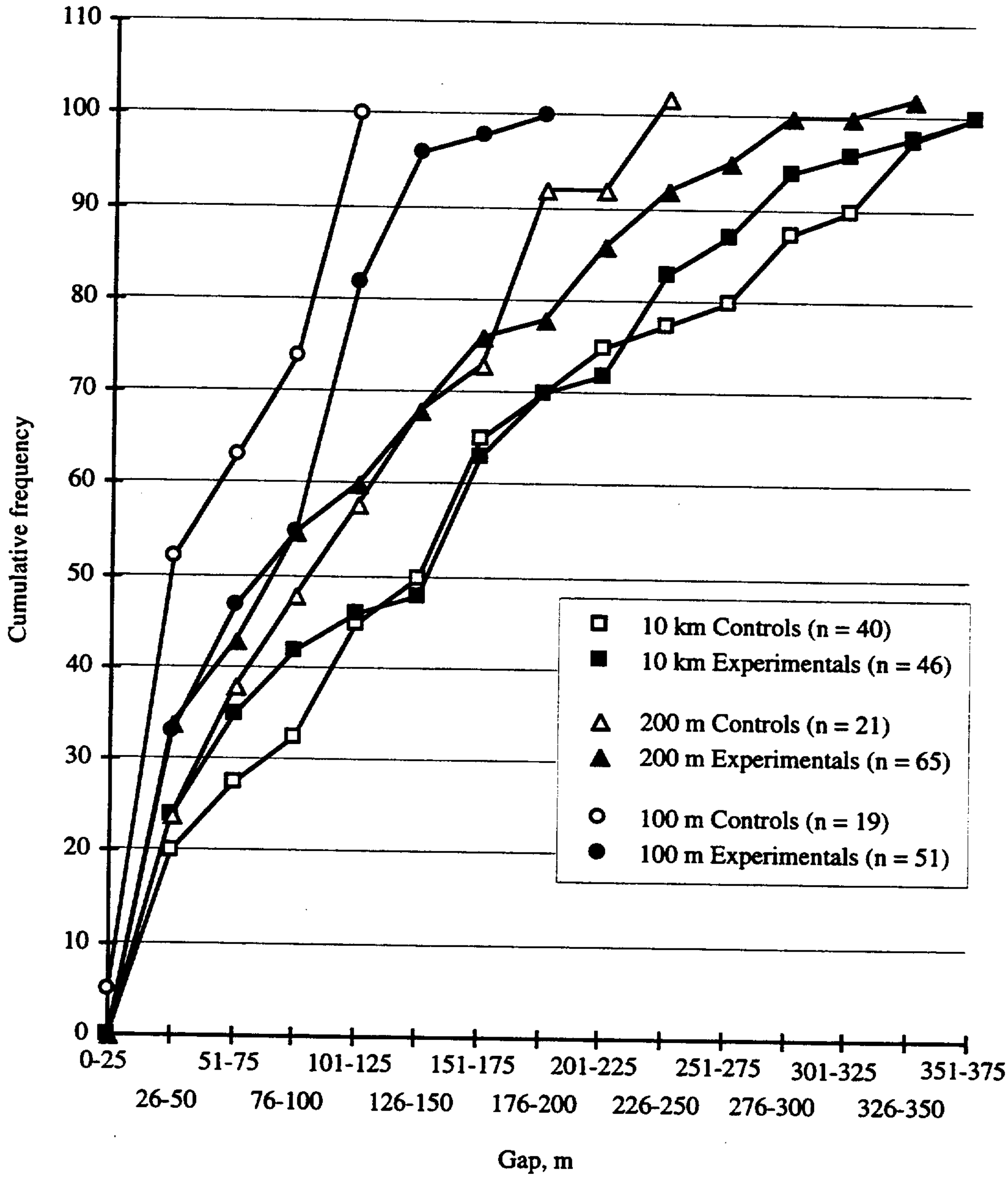

Figure 51. Cumulative frequency of gap size accepted in a lane change by the control and experimental groups. [In the key, n is the number of lane changes plotted. (1 ft = 1 m x 3.28.)]

- As visibility decreased, the size of the gap into which the driver was willing to make a lane change also decreased. For example, when the visibility was 10 km (6.2 mi), 50 percent of the lane changes were into gaps of about 126 m to 150 m (413.3 ft to 492 ft); when the visibility was 100 m (328 ft), 50 percent of the lane changes were into gaps of about 26 m to 75 m (85.3 ft to 246 ft). This tendency seems sensible: With reduced visibility, the two vehicles constituting the ends of a gap would have to be closer together to be simultaneously visible.

For each group for each visibility level there was a cluster of gaps at the small end of the respective ranges (determined from the raw data, which are not shown in the report). These apparently represent the smallest gaps that were acceptable under the conditions of this experiment. The ranges of gap sizes included in these clusters are shown in table 28, both in meters (feet) and, given the group's average velocity, converted to seconds. It is to be noted that the gap sizes in seconds are strikingly similar across visibility conditions and between groups. Whether these times are indicative of general driver behavior cannot be concluded on the basis of a single experiment, but the data are very suggestive.

Table 28. Smallest acceptable gap sizes in lane changes.

	Control Group			Experimental Group		
Visibility Level	Size of Smaller Gaps, m (ft)	Average Velocity, km (mi)/h	Size of Smaller Gaps, s	Size of Smaller Gaps, m (ft)	Average Velocity, km (mi)/h	Size of Smaller Gaps, s
10 km (6.2 mi)	40 through 55 (131 through 180)	83.3 (51.7)	1.7 through 2.4	40 through 55 (131 through 180)	83.3 (51.7)	1.7 through 2.4
200 m (656 ft)	35 through 55 (115 through 180)	78.9 (49.0)	1.6 through 2.3	33 through 55 (108 through 180)	78.9 (49.0)	1.5 through 2.3
100 m (328 ft)	29 through 35 (95 through 115)	67.1 (41.7)	1.6 through 1.9	29 through 44 (95 through 144)	67.1 (41.7)	1.6 through 2.4

Number of Incursions

Lane incursions can provide useful information about the minimum acceptable gap for changing lanes. A lane incursion was defined as an occasion when the driver began to change lanes but, for some reason, did not complete the maneuver and instead returned to the lane from which he/she started. Lane incursions can also provide useful information about the minimum acceptable gap for changing lanes. In the 35-min journey, during which the driver encountered three levels of visibility, there were a total of 187 incursions. Table 29 shows the average number of incursions per driver for younger and older drivers in the control and experimental groups for all three visibility levels.

Table 29. Average number of incursions per driver (rounded to one decimal place) as a function of group, age, and visibility level.

	Control Group		Experimental Group	
Visibility	Age 25-34	Ages 65 and Older	Age 25-34	Ages 65 and Older
10 km (6.2 mi)	1.5	2.6	1.4	2.0
200 m (656 ft)	1.0	0.7	1.0	1.1
100 m (328 ft)	0.8	1.0	0.9	0.6

To determine whether there were any dependencies in the incursion data, they were regrouped into two 2 by 2 contingency tables for chi-squared analyses. Since the averages were too small to allow that statistic to be run, the total numbers of lane changes were used instead. Tables 30 and 31 show the rearranged data.

Table 30. Total number of incursions for each group by visibility-level combination.

Visibility Level	Control Group	Experimental Group
10 km (6.2 mi)	41	54
200 m (656 ft)	17	33
100 m (328 ft)	18	24

Table 31. Total number of incursions for each age by visibility-level combination.

Visibility Level	Age 25-34	Age ≥65
10 km (6.2 mi)	37	58
200 m (656 ft)	26	24
100 m (328 ft)	22	20

For both group by visibility level (table 30) and age by visibility level (table 31) the chi-squared tests on the data failed to reach significance ($\chi^2[2] = 1.2$ and 3.3, respectively; both p's < 0.05). Thus, neither group and visibility level nor age and visibility level were related to each other with respect to number of incursions.

Size of Gap Rejected When Incursions Occurred

No statistical analyses were done on these data. When the visibility was 10 km (6.2 mi) and 200 m (656 ft), incursion gaps longer than 350 m (1148 ft) were omitted; when the visibility was 100 m (328 ft), incursion gaps longer than 200 m (656 ft) were omitted. For the remaining gaps for each group at each visibility level, the number of incursions in each 25-m (82-ft) range was divided by the total number of incursions examined to get the frequency within that range. Then, cumulative frequencies were determined across the entire range of gaps that were plotted. The cumulative frequencies of gap sizes rejected in incursions (subject to the constraints indicated above) are shown in figure 52 for the three visibility levels.

- At 10-km (6.2-mi) and 200-m (656-ft) visibility, the shapes of the plots for the experimental and control groups are very similar, indicating that their behavior did not differ substantially from each other at those visibility levels. At 100-m (328-ft) visibility, there appears to be a tendency toward longer gaps for the experimental group than for the control group; the lack of statistical analysis makes it impossible to tell whether there is a real difference.
- As visibility decreased, the size of the gap into which the driver attempted to make a lane change also decreased. When the visibility was 10 km (6.2 mi), 50 percent of the incursions were into gaps of about 151 m to 175 m (495.3 ft to 574 ft); when the visibility was 100 m (328 ft), 50 percent of the incursions were into gaps of about 26 m to 50 m (85.3 ft to 164 ft).

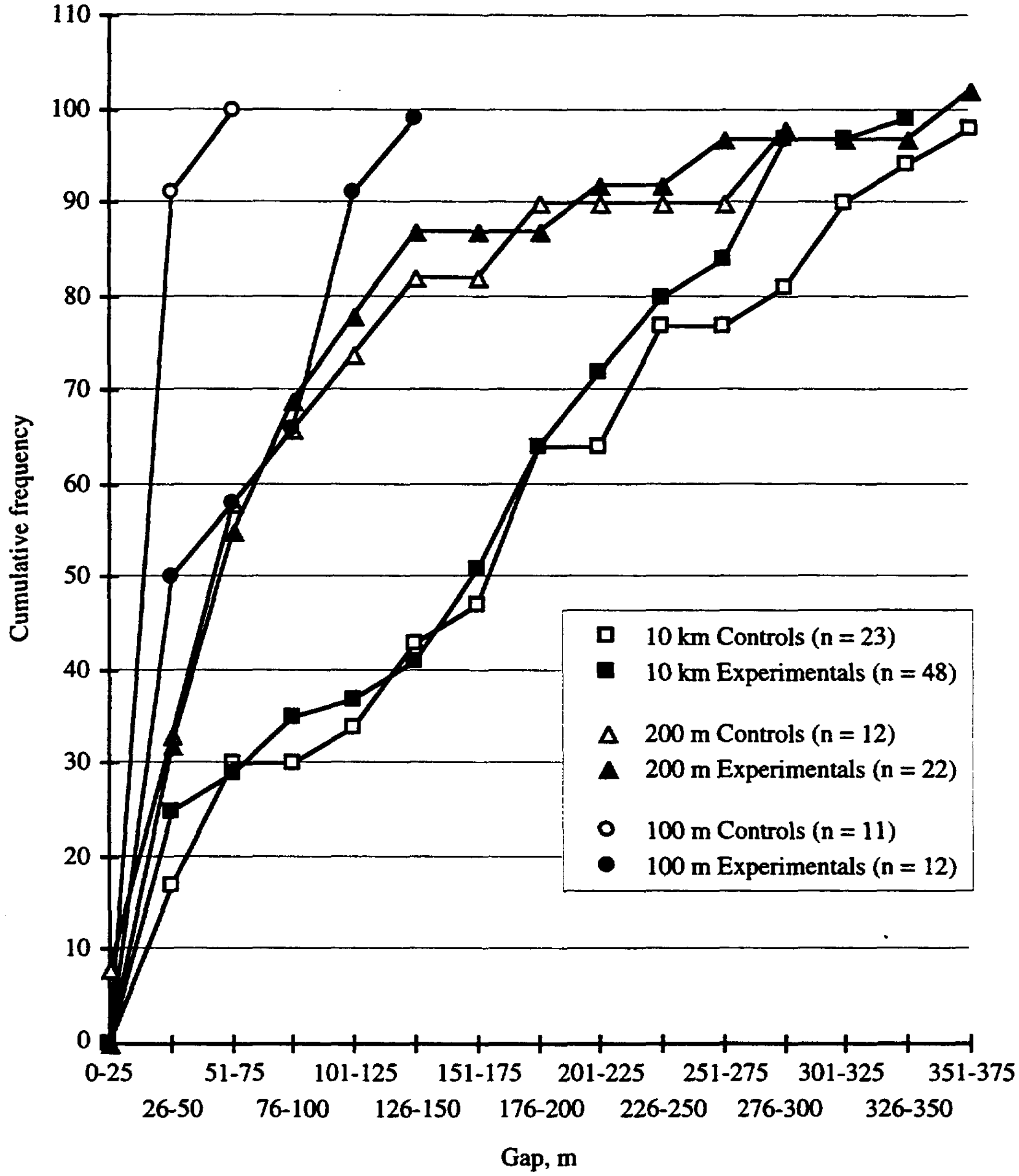

Figure 52. Cumulative frequency of gap size rejected in a lane incursion by the control and experimental groups. In the key, n is the number of incursions plotted. [1 ft = 1 m x 3.28.]

As with the lane-change gaps, there was a cluster of rejected gap sizes at the small end of the respective ranges (determined from the raw data, which are not shown in the report) for each group for each visibility level . These apparently represent gaps that were just below the threshold for acceptability under the conditions of this experiment. The ranges of gap sizes included in these clusters are shown in table 32, both in meters (feet) and, given the group's average velocity, converted to seconds. It is to be noted that, like the smallest gap sizes accepted in lane changes, the

Table 32. Smallest gap sizes rejected in incursions.

	Control Group			Experimental Group		
Visibility Level	Size of Smaller Gaps, m (ft)	Average Velocity, km (mi)/h	Size of Smaller Gaps, s	Size of Smaller Gaps, m (ft)	Average Velocity, km (mi)/h	Size of Smaller Gaps, s
10 km (6.2 mi)	40 through 50 (131 through 164)	83.3 (51.7)	1.7 through 2.2	30 through 53 (98 through 174)	83.3 (51.7)	1.3 through 2.3
200 m (656 ft)	na[1]	na[1]	na[1]	30 through 51 (98 through 167)	78.9 (49.0)	1.4 through 2.3
100 m (328 ft)	29 through 47 (95 through 154)	67.1 (41.7)	1.6 through 2.5	23 through 39 (95 through 115)	67.1 (41.7)	1.2 through 2.1

[1] na means not applicable. There was no clear cluster for the control group at this visibility level. The smallest rejected gap was 30 m (98 ft), which converts to 1.4 s at 78.9 km/h (49.0 mi/h).

rejected gap sizes in seconds are very similar across visibility conditions and between groups. Interestingly, however, the rejected gap sizes are not remarkably different from the accepted gap sizes, though one might have expected them to be noticeably smaller.

QUESTIONNAIRE DATA

There were two versions of the questionnaire used in this experiment: one for the experimental group exposed to the SSGCS and the CWS, and another for those driving in the control condition (i.e., those not exposed to any systems). Questions 1 through 6 were the same for both questionnaire versions. Questions 7 through 24 were given only to those drivers who were exposed to the collision warning and automatic speed, steering, and gap systems. A copy of each questionnaire is presented in appendix 5.

A scale ranging from 0 to 100 with negatively and positively worded anchors at the ends was provided for each question. Drivers were asked to rate their response as a whole number between 0 and 100. A space was provided next to the question and scale. Question 23 was dichotomous, requiring drivers to check a box indicating either yes or no; this item was scored as zero for no and one for yes.

Simulator Realism

The first six questions of the questionnaire were intended to elicit drivers' opinions on the realism of the Iowa Driving Simulator. The average responses for all questions were above 50, indicating positive attitudes toward the simulator. ANOVA's showed only one statistically significant difference for the first six questions—question 3. The data for the other five nonsignificant questions were averaged across age, gender, group, and traffic density. These results appear in table 33.

Responses to 3 of these 6 questions were strong, with means above 70, suggesting that drivers enjoyed driving the simulator (question 1), found the sounds in the simulator to be realistic (question 4), and felt fine while driving the device (question 6). The response to question 5 was moderately strong, suggesting that drivers found the vehicle motion to be realistic. A near-neutral average was reported for question 2, indicating that drivers did not find the simulator very different or very similar to driving in their own car.

As just mentioned, an ANOVA yielded a statistically significant difference for question 3. Responses indicate a positive attitude toward the simulator; however, the magnitude of the response was dependent on group and traffic density. Specifically, drivers exposed to the SSGCS and CWS rated the view out of the windshield as more realistic than drivers not exposed to these systems. Similarly, drivers who drove in low-density traffic rated the view out of the windshield as more realistic than drivers in high-density traffic.

Table 33. Simulator realism (questions 1 through 6).

Question	Overall Mean	
1. How much did you enjoy driving the simulator? 0. Not at all 100. A lot	77.5	
2. How did driving in the simulator compare to driving in your car? 0. Very different 100. Very similar	53.2	
Question	Experimental group	Control group
3. How realistic was the view out of the windshield in the simulator? 0. Very artificial 100. Very realistic	78.75	62.0
	Low Density	High Density
	79.4	65.1
Question	Overall Mean	
4. How realistic were the sounds in the simulator? 0. Very artificial 100. Very realistic	71.3	
5. How realistic was the vehicle motion in the simulator? 0. Very artificial 100. Very realistic	66.5	
6. While driving the simulator, how did you feel? 0. Did not feel well 100. Felt fine	74.9	

Automatic Control

Questions 7 through 10 referred to the automatic control of the collision warning and automatic speed, steering, and gap systems. An ANOVA was carried out on each question. The only statistically significant finding was for question 8, where older drivers indicated that the speed at which they drove under automatic control when there was fog was faster than usual, while younger drivers indicated that the automated speed with fog was somewhat slower than their normal speed. The average responses for questions 7, 9, and 10 are collapsed across age, gender, group, and traffic density. The results, reported in table 34, indicate that the velocity that the

Table 34. Automatic control (questions 7 through 10).

Question	Overall Mean	
7. When your car was under automatic control, how did the speed at which you drove when there was *no* fog compare with the speed at which you usually drive on the highway? 0. My speed was much slower than usual 100. My speed was much faster than usual	54.5	
Question	Younger	Older
8. When your car was under automatic control, how did the speed at which you drove when there was fog compare with the speed at which you usually drive on the highway? 0. My speed was much slower than usual 100. My speed was much faster than usual	46.3	61.4
Question	Overall Mean	
9. When your car was under automatic control, how did the distance between your car and the vehicle ahead when there was *no* fog compare with the usual distance you keep when driving on the highway? 0. The distance was much shorter than usual 100. The distance was much longer than usual	53.7	
10. When your car was under automatic control, how did the distance between your vehicle and the vehicle ahead when there was fog compare with the usual distance you keep when driving on the highway? 0. The distance was much shorter than usual 100. The distance was much longer than usual	51.2	

drivers traveled at while under the control of the SSGCS was close to the speed at which they usually drive on the highway (question 7). Responses also indicated that drivers felt that the distances between their cars and the vehicles ahead in the automated lane was similar to the distances they usually keep when driving on the highway, irrespective of the presence or absence of fog (questions 9 and 10).

Attitude Toward Systems

Questions 11 through 20 referred to drivers' attitudes toward the two in-vehicle systems. An ANOVA was conducted on each question. Statistically significant differences were found for questions 15 and 16. The means for the nonsignificant questions (questions 11 through 14 and 17 through 20), reported in table 35, are collapsed across age, gender, group, and traffic density.

Table 35. Attitude toward in-vehicle systems (questions 11 through 14 and 17 through 20).

Question	Overall Mean
11. If you had the same collision warning system on your vehicle that you had in this experiment, would you use it? 0. Never 100. All the time	77.1
12. If you had the same automated speed, steering, and gap system on your real vehicle that you had in this experiment, would you use it? 0. Never 100. All the time	77.8
13. If you had the same collision warning system on your vehicle that you had in this experiment, how would it affect your safety? 0. It would decrease significantly 100. It would increase significantly	66.6
14. If you had the same speed, steering, and gap system on your real vehicle that you had in this experiment, how would it affect your safety? 0. It would decrease significantly 100. It would increase significantly	70.3

Table 35. Attitude toward in-vehicle systems (questions 11 through 14 and 17 through 20) (continued).

Question	Overall Mean
17. If you had the same collision warning system on your vehicle that you had in this experiment, how would it affect the speed at which you drive? 0. My speed would be much slower 100. My speed would be much faster	56.6
18. If you had the same speed, steering, and gap system on your real vehicle that you had in this experiment, how would it affect the speed at which you drive? 0. My speed would be much slower 100. My speed would be much faster	54.7
19. If you had the same collision warning system on your real vehicle that you had in this experiment, how would it affect the distance between your vehicle and the vehicle ahead? 0. The distance would be much shorter 100. The distance would be much longer	50.2
20. If you had the same speed, steering, and gap system on your real vehicle that you had in this experiment, how would it affect the distance between your vehicle and the vehicle ahead? 0. The distance would be much shorter 100. The distance would be much longer	52.3

Average responses of over 75 for questions 11 and 12 indicated that drivers would use the same CWS in their own vehicle if they had one (question 11) and would use the same SSGCS (question 12) in their own vehicle if they had one. Drivers felt that the same CWS (question 13) and SSGCS (question 14) would increase their safety, as evidenced by the average responses of 66.6 and 70.3, respectively. Although the average responses indicated desires for a somewhat faster velocity and larger intra-string gap distances, drivers expressed neutral opinions about how the CWS and SSGCS would actually affect their speed (questions 17 and 18) or intra-string gap distance (questions 19 and 20).

ANOVA's yielded interactions between age and traffic density for questions dealing with the stress of using these systems on their own vehicles. In question 15, reported in table 36, older drivers in the low-density traffic condition and younger drivers in the high-density traffic condition anticipated a greater reduction in stress from the use of this system on their own vehicles than that reported by older drivers in the high-density traffic condition and younger drivers in the low-density traffic condition. Similarly, as reported in table 37, older drivers in the low-density condition and younger drivers in the high-density traffic condition expressed that the same speed, steering, and gap system installed on their real vehicles would decrease stress more than that reported by older drivers in the high-density condition and younger drivers in the low-density traffic condition (question 16).

Table 36. Attitude toward in-vehicle systems (question 15).

Question		
15. If you had the same collision warning system on your real vehicle that you had in this experiment, how would it affect the stress of driving? 0. Would greatly decrease stress 100. Would greatly increase stress	Younger	Older
Low Density	44.4	28.8
High Density	21.9	38.1

Table 37. Attitude toward in-vehicle systems (question 16).

Question		
16. If you had the same speed, steering, and gap system on your real vehicle that you had in this experiment, how would it affect the stress of driving? 0. Would greatly decrease stress 100. Would greatly increase stress	Younger	Older
Low Density	50.0	27.5
High Density	21.9	36.9

<u>Cruise Control</u>. Questions 23 and 24 referred to the use of cruise control. Results for these questions are presented in table 38. Statistical analysis using ANOVA indicated that significantly

Table 38. Cruise control.

Question	Younger	Older
23. Does your vehicle have cruise control? 0. No 1. Yes	0.44	0.93
Question	**Overall Mean**	
24. How often do you use the cruise control on your vehicle? 0. Hardly ever 100. Almost always	80.2	

more of the older drivers had cruise control in their vehicles than did the younger drivers (question 23). Question 24 asked drivers with cruise control how often they use this feature. No significant differences were found. The mean reported for this question is collapsed across age, gender, group, and traffic density, and indicates that those drivers with cruise control use it quite frequently.

SECTION 4. DISCUSSION

INTRODUCTION

The objectives of the experiment were to determine whether: (1) driving behavior is affected when the driver has access to a SSGCS and to a CWS, (2) driving performance is affected by reductions in visibility, and (3) driving performance is affected by variations in traffic density. Driving-performance data were obtained from 52 drivers: 32 drove with both the SSGCS and CWS, and 20 were controls. The analyses of the data focused on the following experimental questions:

- *Does driving performance change with the use of the SSGCS and CWS?*
- *Is driving performance affected by the age of the driver?*
- *Does driving performance change when the visibility level is reduced?*
- *Does driving performance vary with traffic density?*

There were three operational modes for the intelligent vehicle systems. Each individual participant decided if, when, and for how long each of these modes would be used. Data were collected throughout the 35-min journey, and partitioned according to the choices the driver made about system use. Then, the data analysis focused on the following:

- Driving-performance data that were collected while the driver was using the SSGCS.
- Driving-performance data that were collected while the driver was using the CWS only (i.e., data that were obtained when the CWS was activated and the SSGCS was disengaged).
- Driving-performance data that were collected when both the SSGCS and the CWS were disengaged, but were obtained after the driver had activated the SSGCS at least once.

The analysis was divided into six sections, as is this discussion.

CROSS-EXPERIMENTAL COMPARISON OF THE PERFORMANCE OF CONTROL-GROUP DRIVERS

The driving performance of the drivers in the control group in the current experiment was compared with the driving performance of drivers in the control group in the previous study in this series by Bloomfield, Levitan, Grant, Brown, and Hankey.[8] The performance of the controls in the two experiments was directly compared using 95-percent confidence intervals and the following five driving measures: (a) steering instability, (b) the number of steering oscillations/min, (c) average velocity, (d) velocity instability, and (e) the number velocity fluctuations/min. With each driving measure, there was a large overlap in the confidence intervals for the two sets of data—a result consistent with the view that the driving performance of the control-group drivers in the previous experiment and in the current experiment was essentially the same.

DRIVING WHILE USING THE SSGCS

The performance of drivers who were using the SSGCS was compared with that of the control-group drivers. When the SSGCS was activated, it controlled the steering, the speed of the driver's car, and the distance between the driver's car and the vehicle ahead; the drivers selected the speed of the simulator car and the gap between it and the vehicle directly ahead. Because of this, only the following limited set of comparisons could be made.

Average Velocity. When the average velocity of drivers in the control group was compared with that of drivers in the experimental group while the SSGCS was activated, it was found that using the SSGCS had no effect on the average velocity.

Minimum Following Distance vs. Minimum Gap Setting. The minimum following distance for drivers in the control group was compared with the minimum gap set by drivers in the experimental group. In the two poorest visibility conditions, with the 200-m (656-ft) and 100-m (328-ft) fog, the minimum following distance was shorter for the control-group drivers than the minimum gap set by the experimental-group drivers. In addition, for younger drivers when the visibility was clear, the minimum following distance was shorter for drivers in the control group than the minimum gap set by drivers in the experimental group. It was only for older drivers, when the visibility was clear, that this result was reversed. In this case, the minimum following distance was longer for drivers in the control group than the minimum gap set by drivers in the experimental group. However, it should be noted that, in this case, the minimum gap set by drivers in the experimental group was still relatively large—2.2 s.

Average Actual Gap. The average actual gap of drivers in the control group was compared with both the average actual gap of drivers in the experimental group and with the average gap set by the latter. When the SSGCS was activated, the average actual gap was longer for drivers in the experimental group (3.2 s) than it was for drivers in the control group (2.8 s).

Conclusions. When the driver was using the SSGCS, there was no noticeable effect on the speed at which the driver traveled; however, the driver's car tended to be further behind the vehicle ahead than it was for the control-group drivers who did not have access to the SSGCS.

DRIVING WHILE USING ONLY THE CWS

Unlike the SSGCS, the CWS did not take control of any driving functions; when it was the only system activated, it issued a warning if the driver approached the vehicle ahead too quickly. Driving-performance data obtained from drivers in the experimental group while they were using the CWS alone and from drivers in the control group were compared using the full range of lane-keeping, speed-control, and following-distance measures.

Lane-Keeping Performance. When the experimental-group drivers were using only the CWS, their steering instability was 0.24 m (0.79 ft)—less than the 0.28-m (0.93-ft) steering instability of the control-group drivers. The experimental-group drivers also had more steering oscillations (18.0/min) than the control-group drivers (11.6/min). The experimental-group drivers reduced their steering instability while increasing the number of steering oscillations. They were steering more precisely than the control-group drivers, making more frequent steering correction movements that were much smaller in amplitude than those made by the control-group drivers.

Average Velocity. When the experimental-group drivers were using only the CWS, their average velocity was 2.54 km/h (1.16 mi/h) greater than the controls when the visibility was clear, 2.81 km/h (1.75 mi/h) greater than the controls when the visibility was 200 m (656 ft), and 4.75 km/h (2.95 mi/h) greater than the controls when the visibility was 100 m (328 ft).

Speed Control. When the experimental-group drivers were using only the CWS, their velocity instability was 2.4 km/h (1.5 mi/h), less than the 4.9 km/h (3.0 mi/h) velocity instability of the control-group drivers. They also had many more velocity fluctuations (13.6/min) than the controls (only 2.9/min). The experimental-group drivers reduced their velocity instability while increasing the number of velocity fluctuations. They were controlling the speed more precisely than the control-group drivers, making more frequent speed corrections of much smaller amplitude than those made by the control-group drivers.

Following Distance. When the minimum following distance and the average actual gap of the experimental-group drivers were compared with the minimum following distance and the average actual gap of the control-group drivers, no evidence was found to indicate that group had any effect on either measure.

Conclusions. When the driver was using the CWS alone, the driver controlled both the speed and the steering more precisely than the control-group drivers. It is worth adding a cautionary note. These improvements in performance may be short-lived; they may have occurred only because at those times that the driver decided to use the CWS alone, he/she was very likely to have been paying much more attention than normal to the task of driving. When using the CWS alone, the speed at which the driver traveled was greater than that of the control group drivers. This effect was particularly noticeable in the 100-m (328-ft) fog. Here, it is worth adding an ameliorative note. This more aggressive driving may have occurred because, in some instances, when the driver was using the CWS alone, he/she was likely to have been driving faster than normal specifically because he/she was testing the CWS, as he/she had been invited to when recruited and when given instructions for this experiment. Use of the CWS alone had no noticeable effect on the following-distance measures.

DRIVING WHEN THE SSGCS AND CWS WERE DISENGAGED

Using the SSGCS or CWS did have an effect on some aspects of driving. Now, the possible effect of having used such systems on the driver's subsequent driving behavior is examined. The driving performance of experimental-group drivers, when both intelligent systems were disengaged but after the SSGCS had been activated at least once, was compared with the driving performance of the control-group drivers. The comparison was conducted using the full range of lane-keeping, speed-control, and following-distance measures.

Lane Keeping. When the first lane-keeping measure was used to compare the performance of the drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—with the performance of the control-group drivers, the results were mixed. There was more steering instability for the experimental-group drivers in two combinations of conditions: for older drivers when the visibility was 200 m (656 ft), and for younger drivers when the visibility was 100 m (328 ft). And, there was less steering instability for the experimental-group drivers in the remaining four combinations of conditions: for older drivers when the visibility was clear and when it was 100 m (328 ft), and for younger drivers when the visibility was clear and when it was 200 m (656 ft). In contrast, when the second lane-keeping measure was used to compare the drivers in the experimental group with those in the control group, the experimental-group drivers had more steering oscillations (20.5/min) than the control-group drivers (11.6/min). In this case, the experimental-group drivers increased the number of steering oscillations without changing steering instability. They were making more frequent steering correction movements than the control-group drivers, without changing the steering instability

Average Velocity. The drivers in the experimental group—after the driver had activated the SSGCS at least once, but when both the SSGCS and the CWS were disengaged—had a higher velocity than the drivers in the control group in two cases: with high-density traffic in clear or 100-m (328-ft) visibility. And, the experimental-group drivers had a lower average velocity in four cases: with high-density traffic in 200-m (656-ft) visibility, and with low-density traffic in all three visibility levels.

Speed control. The velocity instability of the experimental-group drivers was 1.9 km/h (1.2 mi/h), less than the 4.9 km/h (3.0 mi/h) velocity instability of the control-group drivers. In addition, the experimental-group drivers had many more velocity fluctuations (13.8/min) than the controls (only 2.9/min). The experimental-group drivers reduced their velocity instability while increasing the number of velocity fluctuations. They were controlling the speed more precisely than the control-group drivers, making more frequent speed corrections of much smaller amplitude than those made by the control-group drivers.

Following Distance. There was no evidence that there was any difference in the minimum following distance of the drivers in the experimental group and in the control group. However, there were differences in the average gap between the two groups. The older drivers in the experimental group had a larger average actual gap than the older drivers in the control group when the visibility was 200 m (656 ft) and 100 m (328 ft), and the younger drivers in the experimental group had a larger average actual gap than the younger drivers in the control group when the visibility was clear. In contrast, older drivers in the experimental group had a smaller average actual gap than older drivers in the control group when the visibility was clear, and younger drivers in the experimental group had a smaller average actual gap than younger drivers in the control group when the visibility was 200 m (656 ft) and 100 m (328 ft).

Conclusion. When the driving performance of the experimental-group drivers—with both intelligent systems disengaged but after the SSGCS had been activated at least once—was compared with the driving performance of the control-group drivers, the results fell into three categories. For three driving-performance measures, steering instability, average velocity, and average actual gap, the results were mixed, with effects in both directions. For one measure, the minimum following distance, there was no noticeable difference in the performance of the drivers in the experimental group and those in the control group. And finally, for the remaining three driving-performance measures, steering oscillations, velocity instability, and the number of velocity fluctuations, there were clear performance differences. The experimental-group drivers had more steering oscillations—they made steering correction movements more frequently than the control-group drivers, but without changing their steering instability. They also reduced their velocity instability while increasing the number of velocity fluctuations. They were controlling the speed of the vehicle more precisely than the control-group drivers, making more frequent speed corrections of much smaller amplitude than those made by the control-group drivers. It should be noted that these changes in driving performance may be short-lived, and may have occurred in this experiment because, as the driver had to decide whether, and when, to use the SSGCS and CWS, he/she may have been paying much more attention than normal to the task of driving.

THE LANE-CHANGING BEHAVIOR OF DRIVERS WITH INTELLIGENT VEHICLE SYSTEMS

As visibility decreased, the average number of lane changes apparently increased for the experimental group while staying approximately constant for the control group. It is to be noted that, when the experimental group had the collision warning system on alone, although both groups reduced their average velocities as visibility decreased, the experimental group's did not decrease as rapidly. Perhaps the two effects are correlated in that the experimental group changed lanes more frequently in the service of maintaining a higher average velocity. It is also to be noted, however, that average velocities were relatively low throughout the experiment: at 10-km (6.2-mi) visibility, average velocities were less than 84 km/h (about 52 mi/h) for both groups; at 100-m (328-ft) visibility, average velocities were about 70 km/h (about 43 mi/h) or less for both groups.

Regarding age, the older drivers maintained a relatively constant average number of lane changes across visibility levels, but the younger drivers apparently increased their average number of lane changes as visibility decreased. It is tempting to conclude that the younger drivers were more aggressive than the older drivers, but the average velocities do not support aggressiveness as a mediator: Both groups decreased their average velocities as visibility decreased, and the decrease was more rapid for the younger drivers. In addition, although the fastest average velocity at any visibility level was for the younger drivers at 10-km (6.2-mi) visibility, it was still less than 87 km/h (54 mi/h), while the posted speed limit was 88.6 km/h (55 mi/h). It is not clear what the explanation is for the interaction between age and visibility level on average number of lane changes.

IMPLICATIONS FOR THE AHS

- The fact that use of the SSGCS, which was essentially an intelligent cruise control system plus a lane-keeping capability, had no obvious effect on average velocity or minimum following distance/gap setting may bode well for the AHS. If this outcome is replicated, it will mean that drivers can get the benefits of such automation (e.g., a less stressful trip, better fuel efficiency, reduced pollutants in the air) without any obvious negative effects (such as higher speeds and shorter gaps).
- While the collision warning system was on alone, on the other hand, lane keeping (as steering instability) and speed maintenance (as velocity instability) were both better for the experimental group than for the control group. Both effects were also seen—"carried over to?"—when both automation systems were disengaged after the SSGCS had been on at least once. Though these appear to be positive effects, they may in fact not be. First, the performance differences may not have had any practical significance: lane keeping is typically adequate for the great majority of drivers (as it was in this experiment), and overall speed was generally quite low, ranging from about 66 km/h (41 mi/h) to 84 km/h (52.2 mi/h). Second, and perhaps more important, it may be that the experimental drivers' better performance was at the expense of situation awareness: Because they were paying more attention to staying in their lane and holding a constant speed, they may have been paying less attention to the more global situation around them regarding potential obstacles and the like. The fact that lane keeping was poorer (steering instability was higher) for both the experimental and control groups in high-density traffic than in low-density traffic lends some support to this notion: In high-density traffic, attending to the more global situation was more important because of the presence of more vehicles, and thus drivers were less able to attend to their lane-keeping behavior. (Of course, this does not explain the incremental effect of having the collision warning system on.) At any rate, the hypothesis that improved driving behavior along some dimensions comes at the expense of poorer performance along other dimensions deserves careful study.

- When the collision warning system was on alone, there was also an interaction between group and visibility level on average velocity: Although both groups reduced their speeds as the visibility decreased, the difference between the groups increased as visibility decreased. At 10-km (6.2-mi) visibility, the experimental group drove an average of 2.5 km/h (1.6 mi/h) faster than the control group, while at 100-m (328-ft) visibility they drove an average of 4.8 km/h (3.0 mi/h) faster. Though the absolute differences are not great, the trend is not a good one. It is as if the driver believed that the warning would compensate for his/her increased (relative) speed, and this seems a potentially dangerous game to play.
- There was an apparent increase in the number of lane changes for the experimental group as the visibility decreased, and this occurred either when the collision warning system (CWS) was on alone or when neither system was on (the data did not differentiate between these possibilities). As has been discussed above, when the experimental group was using the collision warning system, drivers did not reduce their speed as much as did those in the control group when the visibility decreased. Thus, the increase in the number of lane changes may be another reflection of the experimental-group drivers' using the CWS as a basis for driving faster than drivers who did not have the system available.
- Use of the collision warning system led to some driver behavior that merits further investigation before such a system could be recommended for actual use.
- On the questionnaire, drivers indicated they would use either automated system if it were available on their real vehicles, and that neither system would affect their speed or intervehicle gap. These attitudes are positive preliminary indications that such automation may be favorably received.

APPENDIX 1: MAP OF THE VISUAL DATABASE

Each driver drove a fixed-time route starting at Exit 7 (County Rd E) heading counterclockwise (see figure 53).

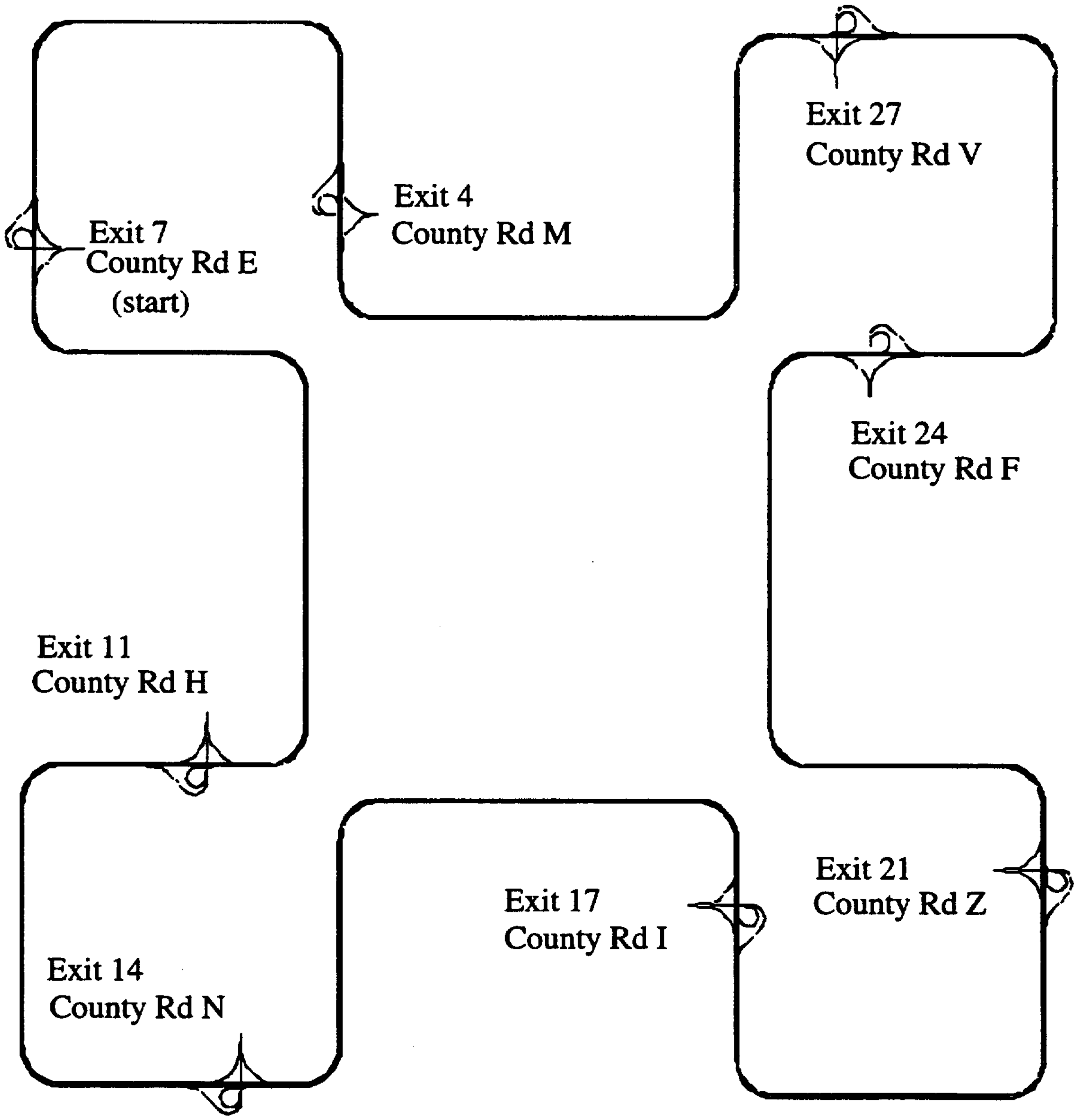

Figure 53. Map of the route driven in the experiment.

APPENDIX 2: ORDER OF PRESENTATION OF CONDITIONS

The between-subjects variables, traffic density and group, were balanced across age and gender. Young males and young females were between the ages of 25 and 34. Older males and older females were between the ages of 65 and 69 and 75+ respectively. There were two possible traffic densities. The low density was 6.21 v/km/ln (10 v/mi/ln); the high density was 12.42 v/km/ln (20 v/mi/ln).

Table 39. The traffic-density condition experienced by younger[1] male drivers.

Driver[2]	Traffic Density
YM B01	Low density
YM B02	High density
YM B03	**CONTROL 20**
YM B04	Low density
YM B05	High density
YM B06	**CONTROL 10**
YM B07	Low density
YM B08	High density
YM B09	**CONTROL 20**
YM B10	Low density
YM B11	High density
YM B12	**CONTROL 20**
YM B13	**CONTROL 10**

[1] Younger drivers were between the ages of 25 and 34.
[2] *YM* means younger male.

Table 40. The traffic-density condition experienced by younger[1] female drivers.

Driver[2]	Traffic Density
YF B01	High density
YF B02	**CONTROL 20**
YF B03	Low density
YF B04	High density
YF B05	**CONTROL 10**
YF B06	Low density
YF B07	High density
YF B08	**CONTROL 10**
YF B09	Low density
YF B10	High density
YF B11	**CONTROL 20**
YF B12	Low density
YF B13	**CONTROL 10**

[1] Younger drivers were between the ages of 25 and 34.
[2] *YF* means younger female.

Table 41. The traffic-density condition experienced by older[1] male drivers.

Driver[2]	Traffic Density
OM B01	**CONTROL 20**
OM B02	High density
OM B03	Low density
OM B04	**CONTROL 10**
OM B05	High density
OM B06	Low density
OM B07	**CONTROL 10**
OM B08	**CONTROL 10**
OM B09	High density
OM B10	Low density
OM B11	**CONTROL 20**
OM B12	High density
OM B13	Low density

[1] Older drivers were between the ages of 65 and 69 (OM B01 through OM B06) and 75+ (OM B07 through OM B13).

[2] *OM* means older male.

Table 42. The traffic-density condition experienced by older[1] female drivers.

Driver[2]	Traffic Density
OF B01	Low density
OF B02	**CONTROL 10**
OF B03	High density
OF B04	Low density
OF B05	**CONTROL 20**
OF B06	High density
OF B07	Low density
OF B08	**CONTROL 20**
OF B09	High density
OF B10	Low density
OF B11	**CONTROL 10**
OF B12	High density
OF B13	**CONTROL 20**

[1] Older drivers were between the ages of 65 and 69 (OF B01 through OF B06) and 75+ (OF B07 through OF B13).

[2] *OF* means older female.

APPENDIX 3: NARRATIVE FOR THE TRAINING VIDEOS

INTRODUCTION

Each driver who took part in this experiment was shown a videotape containing introductory material and experimental instructions. Two different versions of the video were produced: one for the group of drivers who drove with the intelligent vehicle systems, the other for the drivers in the control group.

VIDEOTAPE #2.1

This was used for the drivers who drove with the intelligent vehicle systems.

[A. Introduction]

[Camera position #1]

Passage A.1: The study in which you are about to participate is part of an ongoing investigation of advanced automobile technology. We are conducting the investigation for the FHWA, the Federal Highway Administration. The FHWA is responsible for safety and travel effectiveness on our highways. In this investigation, the FHWA is trying to determine whether newly developed technology will help to reduce congestion and to increase highway safety. We are conducting a series of studies using the Iowa Driving Simulator. We will determine how well the advanced technology might work, and how easy it is for drivers to use. The data provided by you, and others, will aid us in making accurate and responsible recommendations about how advanced automobile technology should be designed and used. This is a test of the technology, not a test of you or your driving skills. We will maintain your privacy—your data will never be presented with your name attached.

[Camera position #2]

Passage A.2: The car that you will drive in the simulator has been equipped with two advanced technology systems. The first is a Speed, Steering, and Gap Control System that will maintain whatever speed you set, keep your car in the lane you choose, and maintain the distance from the vehicle ahead. The second system is a Collision Warning System that will warn you if you approach the vehicle ahead of you too fast.

[B. The Speed, Steering, and Gap Control System]

[Camera position #2]

Passage B.1: Let me explain how the Speed, Steering, and Gap Control System works. When you first switch on the system, it will automatically maintain the speed at which your car is currently moving. It will also keep you as far from the vehicle ahead of you as you are when you turn on the system—with two exceptions. The exceptions are that if the vehicle ahead is far away from you, the system will set the gap to the maximum; and if you are too close to the vehicle, the system will set the gap to the minimum. The system will maintain whatever speed you set, keep your car in the lane you choose, and maintain the distance from the vehicle ahead.

[Camera position #2]

Passage B.2: If the vehicle ahead is traveling slower than you are, you will gradually catch up to it. As long as the distance between you and the vehicle ahead is greater than the gap that you selected, you will continue to get closer to that vehicle. When the distance between you and the vehicle ahead is equal to the gap you selected, your car will slow down and maintain the selected gap.

[C. Switching on the Speed, Steering, and Gap Control System]

[Camera position #2]

Passage C.1: A control panel is used to switch on both systems. It will be located to your right in the car.

[Camera position #2]

Passage C.2: At the top of the control panel you will see a message display. Below the message display, there are two sets of controls. The controls to the right are for the collision warning system—we will talk about them later. The controls located to the left of the control panel are marked *Speed, Steering,* and *Gap*.

[Camera position #2]

Passage C.3: To switch on the speed, steering, and gap controls, you press the *Set* key. As soon as the *Set* key is pressed, the Speed, Steering, and Gap control systems will be activated. You will know that they are switched on because the *Systems-on* indicator will be illuminated and, on the display above the controls, you will see a message informing you that the automated systems are on.

[D. Setting the Speed]

[Camera position #2]

Passage D.1: When you switch the system on, a speed and gap will automatically be set—the speed and gap setting are indicated on the message display. The speed of your car at the time you turn on the system will be the initial speed setting.

[Camera position #2]

Passage D.2: You can select a different speed setting by using the rocker switch marked *Speed.* To increase the speed setting, you press the top of the rocker switch, where there is an arrow pointing upward. To decrease the speed setting, you press the bottom of the rocker switch, where there is an arrow pointing downward. The speed setting that you select will be indicated on the message display. The minimum speed setting is 30 miles an hour.

[E. Setting the Gap]

[Camera position #2]

Passage E.1: When you switch on the system, the gap as well as the speed will be set automatically. Usually, the gap will be set at the current distance between you and the vehicle ahead. But, if you are less than 0.5 seconds away, the gap will be set at 0.5 seconds; and, if you are more than 5 seconds away, the gap will be set at 5 seconds.

[Camera position #2]

Passage E.2: You can also change the gap setting. By doing this you will change the distance at which your car will follow a vehicle in the lane ahead of you.

[Camera position #2]

Passage E.3: You can select a different gap setting by using the rocker switch marked *Gap*. To reduce the gap setting—and travel closer to the vehicle ahead—you press the bottom of the rocker switch, where there is an arrow pointing downward. To increase the gap setting—so that you increase the distance to the vehicle ahead—you press the top of the rocker switch, where there is an arrow pointing upward. The gap setting that you select will be indicated on the message display. The maximum gap setting is 5 seconds, the minimum is 0.5 seconds.

[F. Disengaging the Speed, Steering, and Gap Control System]

[Camera position #2]

Passage F.1: You will disengage the speed, steering, and gap control system if you press the accelerator or brake pedal, or if you move the steering wheel as you would to change lanes. In each case, you will regain control of the speed and the steering, and you will hear the following message:

["System off. You must steer and control your speed."]

[G. Re-engaging the Speed, Steering, and Gap Control System]

[Camera position #2]

Passage G.1: You may choose to disengage the speed, steering, and gap control system for various reasons—for example, because you are changing lanes or overtaking another vehicle. Once the maneuver is complete, you may wish to re-engage the system and keep the same speed and gap settings that you had before the maneuver—to do this you must press the *Resume* key.

[Camera position #2]

Passage G.2: After the maneuver is complete, you may want to re-engage the system, but with different speed and gap settings. There are two ways of doing this: you can either press the *Resume* key, and use the *Speed* and *Gap* rocker switches to make the changes; or, before switching the system back on, you can get to the new speed and gap that you want, and then press the *Set* key

[H. Activating the Collision Warning System]

[Camera position #2]

Passage H.1: You can operate the Collision Warning System by using the controls on the right of the control panel.

[Camera position #2]

Passage H.2: To switch on the Collision Warning System, you press the *Collision Warning* key. The system will be activated and the *Collision Warning* indicator will be illuminated.

[Camera position #2]

Passage H.3: When this system is operating, if you are approaching the vehicle ahead of you in your lane so rapidly that you are in danger of colliding with it, the accelerator pedal will automatically push up against your foot. If you feel the accelerator pedal pushing against your foot, you should slow down immediately.

[I. Activating the Collision Warning System]

[Camera position #2]

Passage H.3: If you wish to disengage the Collision Warning System, you should press the *Collision Warning* key. When it is pressed the system will go off.

VIDEOTAPE #2.2

This was used for the drivers in the control group.

[A. Introduction]

[Camera position #1]

Passage A.1: The study in which you are about to participate is part of an ongoing investigation that we are conducting for the FHWA, the Federal Highway Administration. The FHWA is responsible for safety and travel effectiveness on our highways. In this investigation, the FHWA is trying to determine how to design our future highways in order to reduce congestion and to increase highway safety. We are conducting a series of studies using the Iowa Driving Simulator. The data provided by you, and others, will aid us in making accurate and responsible recommendations about how to design and operate new highway systems. This is a test of future highway systems, not a test of you or your driving skills. We will maintain your privacy—your data will never be presented with your name attached.

[B. Driving on the Freeway]

[Camera position #2]

Passage B.1: Today we will ask you to drive for an extended time in a three-lane freeway. At the start of the drive, your car will be parked on a freeway entrance ramp. You will drive from the entrance ramp into the right lane.

[Camera position #2]

Passage B.2: While you are in the freeway, you will drive among vehicles that will behave in the way that traffic usually behaves on a freeway. The speed limit is 55 miles per hour.

APPENDIX 4: INTELLIGENT VEHICLE SYSTEM TRAINING DEVICE AND INSTRUCTIONS FOR TRAINING

The following instructions were given to each driver in the group who drove using the intelligent vehicle system in order to train them in the use of the system. When the instructions were given, each driver was shown a mock version of the device installed on a laptop computer. The interface for this mock device is shown in figure 54.

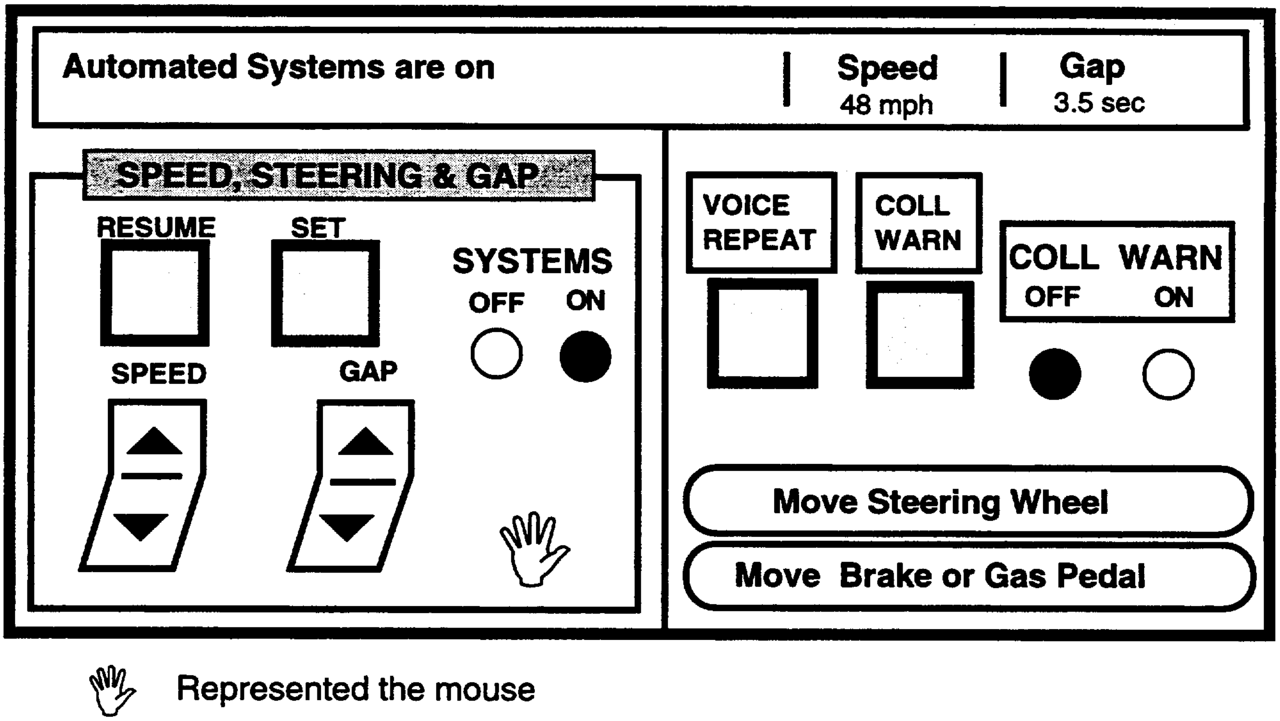

Figure 54. Interface for the laptop version of the intelligent vehicle system, used to train drivers.

INSTRUCTIONS FOR TRAINING THE INTELLIGENT VEHICLE SYSTEM GROUP OF DRIVERS

EXPERIMENTER:

> Now, I'd like you to practice using the Speed, Steering, and Gap Control System.
> Use the computer on your right.
> When you are driving you will be able to press the keys on the system directly.

Now you should move the mouse over to the keys and click on them.

The *Speed, Steering,* and *Gap* controls are to the left of the control panel.
To start the system, move to the *Set* key—and click on it.
You will see the *Systems on* indicator is lit
And, in the dialogue box to the left there is a message saying the automated systems are on.
To the right you can see an example of what your current speed and gap might be.

To change the speed setting, you can press the rocker switch marked *Speed.*
To increase the speed setting, click on the arrow pointing upward.
To decrease the speed setting, click on the arrow pointing downward.
The speed setting shows the speed that you would like to travel at.
—Remember, the speed that you are actually traveling at is given by the speedometer.

To change the gap, move to the rocker switch to the right.
You can reduce the gap setting by clicking on the arrow pointing upward.
You can increase the gap setting by clicking on the arrow pointing downward.

Do you have any questions?
[If the driver says he/she doesn't know what gap to set, and asks for a recommendation, you can say:
"The Iowa State Patrol recommends that when drivers are driving manually, they should keep 2 seconds behind the vehicle ahead."]

When the Speed, Steering, and Gap Control System is on, your speed will be controlled by the speed setting—that is, the system will try to take you along at the speed you set—until the distance to the vehicle ahead is the same as the gap setting.
Then the vehicle will slow down and maintain the gap.
To turn off the Speed, Steering, and Gap Control System, you press the brake or accelerator pedal or move the steering wheel.
You can do that now by clicking on one of them now.
If you do one of these, you will regain control of the speed and the steering, and you will hear the message that you see now in the dialogue box.
To listen to the message again, press the *Voice Repeat* key.

To re-engage the Speed, Steering, and Gap Control System and keep the same speed and gap settings that you had before, you must press the *Resume* key.

You can operate the Collision Warning System by using the controls on the right of the control panel.
Click on the *Collision Warning* key.
The system will be activated and the *Collision Warning* indicator will be lit.
When the Collision Warning System is on, if you are approaching the vehicle ahead so rapidly that you are in danger of colliding with it, the accelerator pedal will automatically push up against your foot.
If you feel the accelerator pedal pushing against your foot, you should be prepared to use the brake to slow down.
Remember, it is a warning system, it will not slow your car down, you have to do that.

To turn off the Collision Warning System, you should press the *Collision Warning* key.

If both systems are on, the Speed, Steering, and Gap Control System will stop you from getting too close to the car ahead.

Please switch on the Speed, Steering, and Gap Control System.
Please change the speed.
Please change the gap.
Please switch off the Speed, Steering, and Gap Control System.
Please switch on the Collision Warning System.
Please switch off the Collision Warning System.

APPENDIX 5: QUESTIONNAIRES

The following questionnaires deal with subject background, certain aspects of the driving simulator, the study that the participants took part in, and the use of new technology (as described in the introduction). There is a different questionnaire for each group: one for the experimental group (free agent condition) and one for the control condition.

Questionnaire for the Experimental Group

Instructions

The following series of questions deals with the driving simulator, the experiment that you just took part in, and advanced automobile technologies. For most of the questions, you will be asked to provide a rating from 0 to 100. The meanings of the two endpoints of the scale are provided for each question. Your answer can be any whole number between 0 and 100; do not use fractions or decimals. A space is provided for you to write your answer in.

Example:

Question	Scale	Your Rating
How would you rate the importance of air bags in driver safety?	0 = Very unimportant 100 = Very important	________

If you think that air bags are pretty important in driver safety, you would provide a rating of over 50; the more important you think they are, the closer your rating would be to 100. If you think that air bags are not too important, you would provide a rating of less than 50; the more *un*important you think they are, the closer your rating would be to 0.

Questions

Question	Scale	Your Rating
1. How much did you enjoy driving the simulator?	0 = Not at all 100 = A lot	________
2. How did driving in the simulator compare to driving in your car?	0 = Very different 100 = Very similar	________
3. How realistic was the view out of the windshield in the simulator?	0 = Very artificial 100 = Very realistic	________
4. How realistic were the sounds in the simulator?	0 = Very artificial 100 = Very realistic	________
5. How realistic was the vehicle motion in the simulator?	0 = Very artificial 100 = Very realistic	________
6. While driving the simulator, how did you feel?	0 = Did not feel well 100 = Felt fine	________

Question	Scale	Your Rating
7. If you had the same automated Speed, Steering, and Gap system on your real vehicle that you had in this experiment, would you use it?	0 = Never 100 = All the time	____________
8. If you had the same Speed, Steering, and Gap system on your real vehicle that you had in this experiment, how would it affect your safety?	0 = It would decrease significantly 100 = It would increase significantly	____________
9. If you had the same Speed, Steering, and Gap system on your real vehicle that you had in this experiment, how would it affect the stress of driving?	0 = Would greatly decrease stress 100 = Would greatly increase stress	____________
10. If you had the same Speed, Steering, and Gap system on your real vehicle that you had in this experiment, how would it affect the speed at which you drive?	0 = My speed would be much slower 100 = My speed would be much faster	____________
11. If you had the same Speed, Steering, and Gap system on your real vehicle that you had in this experiment, how would it affect the distance between your vehicle and the vehicle ahead?	0 = The distance would be much shorter 100 = The distance would be much longer	____________

Question	Scale	Your Rating
12. If you had the same Collision Warning system on your real vehicle that you had in this experiment, would you use it?	0 = Never 100 = All the time	________
13. If you had the same Collision Warning system on your real vehicle that you had in this experiment, how would it affect your safety?	0 = It would decrease significantly 100 = It would increase significantly	________
14. If you had the same Collision Warning system on your real vehicle that you had in this experiment, how would it affect the stress of driving?	0 = Would greatly decrease stress 100 = Would greatly increase stress	________
15. If you had the same Collision Warning system on your real vehicle that you had in this experiment, how would it affect the speed at which you drive?	0 = My speed would be much slower 100 = My speed would be much faster	________
16. If you had the same Collision Warning system on your real vehicle that you had in this experiment, how would it affect the distance between your vehicle and the vehicle ahead?	0 = The distance would be much shorter 100 = The distance would be much longer	________

17. Do you have any comments on the automated systems you used in this experiment?

____

____

____

____

____

18. What type of vehicle do you *usually* drive? Please check one and indicate the make and year.

	Make	Year
❑ Car	__________	______
❑ Van	__________	______
❑ Truck	__________	______
❑ Motorcycle	__________	______
❑ Other (specify) __________	__________	______

19. Does your vehicle have cruise control?

- ❑ Yes (Please go to question 20.)
- ❑ No (Stop. You have completed the questionnaire.)

Question	Scale	Your Rating
20. How often do you use the cruise control on your vehicle?	0 = Hardly ever 100 = Almost always	__________

Questionnaire for the Control Group

Instructions

The following series of questions deals with the driving simulator and the experiment that you just took part in. For most of the questions, you will be asked to provide a rating from 0 to 100. The meanings of the two endpoints of the scale are provided for each question. Your answer can be any whole number between 0 and 100; do not use fractions or decimals. A space is provided for you to write your answer in.

Example:

Question	Scale	Your Rating
How would you rate the importance of air bags in driver safety?	0 = Very unimportant 100 = Very important	________

If you think that air bags are pretty important in driver safety, you would provide a rating of over 50; the more important you think they are, the closer your rating would be to 100. If you think that air bags are not too important, you would provide a rating of less than 50; the more *un*important you think they are, the closer your rating would be to 0.

Questions

Question	Scale	Your Rating
1. How much did you enjoy driving the simulator?	0 = Not at all 100 = A lot	________
2. How did driving in the simulator compare to driving in your car?	0 = Very different 100 = Very similar	________
3. How realistic was the view out of the windshield in the simulator?	0 = Very artificial 100 = Very realistic	________
4. How realistic were the sounds in the simulator?	0 = Very artificial 100 = Very realistic	________
5. How realistic was the vehicle motion in the simulator?	0 = Very artificial 100 = Very realistic	________
6. While driving the simulator, how did you feel?	0 = Did not feel well 100 = Felt fine	________

7. What type of vehicle do you *usually* drive? Please check one and indicate the make and year.

		Make	Year
❑	Car	________	_____
❑	Van	________	_____
❑	Truck	________	_____
❑	Motorcycle	________	_____
❑	Other (specify) ________	________	_____

8. Does your vehicle have cruise control?

❑ Yes (Please go to question 9.)

❑ No (Stop. You have completed the questionnaire.)

Question	Scale	Your Rating
9. How often do you use the cruise control on your vehicle?	0 = Hardly ever 100 = Almost always	________

APPENDIX 6: DRIVING MEASURES

Using ideas derived from regression analysis, Bloomfield and Carroll developed a set of lane-keeping and speed-control measures.[19] They showed how to determine two linear equations. The first of these is a lane-keeping equation that represents the line of best fit for a series of points that indicate the offset of the center of a vehicle from the center of the lane, as the vehicle travels along the freeway. The second is a speed-control equation that represents the line of best fit for a second series of points that indicate the velocity of the vehicle, as it travels along the freeway.

The lane-keeping equation describes the position of the vehicle relative to the center of the lane at a given time. It indicates how far the vehicle is offset to the left or right of the center line of the lane. It also shows whether the vehicle is veering to the left or to the right or is traveling parallel to the lane throughout the series of points. The variability of the actual track of the vehicle around this line of best fit is used, along with the number of crossings of the direction of travel (or line of best fit), to indicate the stability of the driver in maintaining the track of the vehicle. In the current experiment, data were collected at a rate of 30 Hz, so that, as the vehicle traveled along a straight road segment, the track of the vehicle could be used to determine the position of the center of the vehicle relative to a series of perpendicular lines drawn at 1/30-s intervals. Bloomfield and Carroll assume that the series of positions could be described by the following linear equation:

$$p = a_{lk} - b_{lk}x \qquad (1)$$

where:

- p is the point (representing the center of the driver's vehicle) at which the line of best fit crosses the perpendicular across the lane after the vehicle has traveled distance x.
- x is the distance traveled in the lane by the vehicle.
- a_{lk} is the point at which the line of best fit crosses the perpendicular at the start of the straight road segment.
- b_{lk} is the gradient of the line of best fit—it is essentially the steering drift.

The series of positions of the center of the vehicle is unlikely to fall exactly on a straight line. However, since in comparison to the 3.66-m (12-ft) width of the lane, the vehicle will travel along what is, relatively speaking, a very long, straight road segment, it is not unreasonable to assume that the series of positions can be described by a linear equation. Because the equation suggested by Bloomfield and Carroll is a linear regression equation, the line of best fit of this equation can be calculated using the method of least squares. Using the method of least squares, which minimizes the error in predicting p from x, the terms a_{lk} and b_{lk} are calculated as follows:

$$b_{lk} = \frac{\sum xp - \frac{(\sum x)(\sum p)}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{2}$$

where n is the number of data points obtained while the vehicle travels distance x, and

$$a_{lk} = \frac{1}{n}(\sum p - b_{lk} \sum x) \tag{3}$$

In addition, the variability in b_{lk}, the residual standard deviation, can be used as an estimate of I_{lk}, the steering instability. I_{lk} provides an estimate of the variability in steering that occurs when the driver is attempting to maintain a straight course along the line of best fit. It is given by the equation:

$$I_{lk} = \sqrt{\left[\sum p^2 - \frac{(\sum p)^2}{n} - \frac{\left\{\sum xp - \frac{(\sum x)(\sum p)}{n}\right\}^2}{\sum x^2 - \frac{(\sum x)^2}{n}}\right] \div (n-2)} \tag{4}$$

Equations 1 and 2 define the position of a vehicle in a straight road segment; equation 3 gives information on steering drift across the lane (if there is any); and equation 4, along with the number of crossings of the direction of travel (or steering oscillations), provides a measure of the smoothness or stability of the ride.

If there were to be a radical change in the direction of the vehicle, and the most radical change that could occur while the vehicle remains in the lane would occur if, for example, the vehicle first veered from the extreme right of the lane to the extreme left, then changed direction and veered from the extreme left back to the extreme right of the lane, then the measures would indicate the radical change, since the steering instability would be relatively large but there would be only two steering oscillations.

The current experiment explored the driving performance of drivers while they were driving on a straight and curved segments of expressway both before and after they had experienced traveling under automated control. Bloomfield and Carroll also demonstrated that it is possible to use this linear equation to describe the track of vehicle traveling around a horizontal curve, as long as the position of the vehicle in the lane is determined relative to the cross-section of the lane.(14) When the road is curved and the position of the vehicle in the lane is determined relative to the cross-section of the lane, then at each moment the position of the vehicle will be expressed relative to a line that is perpendicular to the tangent of the curve. In the current experiment, data were collected at a rate of 30 Hz. As a result, around every curve there was a series of tangents at 1/30-s intervals, each with a cross-sectional line that was perpendicular to it. The points at which the track of the vehicle intersected those cross-sectional lines, spaced 1/30-s apart, constituted the lane-position data.

To determine how the lateral position of the vehicle across the lane varies as it travels around a curve, the series of cross-sectional lines are considered together. Since the data were not collected continuously, but rather at intervals that were 1/30-s apart, there are segments of roadway between the cross-sectional lines where data were not collected. Note that this is true whether the road is curved or straight. On a straight road, the segments where data are not collected are rectangular; on a curved road they are wedge-shaped. In either case, because the segments are so small—when the data rate is high, as it was in this experiment—they can be ignored for purposes of statistical analysis. Because this is true, it does not matter for the analysis whether the roadway was straight or curved. A *linear* regression can be applied to the series of points indicating the position of the vehicle in the lane for both situations. Therefore, the set of equations presented above could be used to derive the values of the lane-keeping and speed-control measures from the data collected in the current experiment.

A set of equations similar to those used to describe lane-keeping performance can be used to describe the driver's ability to control the speed of the vehicle. In this case, there are two speed-control measures—the first is a measure of the velocity at any instant, the other a measure of whether the velocity is drifting higher or lower—and a measure of the stability of speed control. The speed-control stability measure can be used with the number of steering oscillations, i.e., the number of velocity reversals across the line of best fit (or velocity maintenance line). The equations used in this case differ in that p, a_{lk}, b_{lk}, *and* I_{lk} in equations 1, 2, 3, and 4 are replaced by v, a_{sc}, b_{sc}, *and* I_{sc}, respectively, in equations 5, 6, 7, and 8. Equations 5, 6, and 7 provide a description of how well the driver maintains velocity, while equation 8 is a measure of smoothness or stability in maintaining velocity. These equations are presented below:

$$v = a_{sc} + b_{sc}x \tag{5}$$

$$b_{sc} = \frac{\sum xv - \frac{(\sum x)(\sum v)}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{6}$$

$$a_{sc} = \frac{1}{n}(\sum v - b_{sc}\sum x) \tag{7}$$

$$I_{sc} = \sqrt{[\sum v^2 - \frac{(\sum v)^2}{n} - \frac{\{\sum xv - \frac{(\sum x)(\sum v)}{n}\}^2}{\sum x^2 - \frac{(\sum x)^2}{n}}] \div (n-2)} \tag{8}$$

where:

- v is the velocity, indicated by the line of best fit, after the vehicle has traveled distance x.
- a_{sc} is the point at which the line of best fit intercepts the velocity axis at the start of the straight road segment.
- b_{sc} is the gradient of the line. If b_{sc} equals zero, the vehicle is traveling at a constant velocity; if b_{sc} is positive, the velocity of the vehicle is gradually increasing; and if b_{sc} is negative, velocity is gradually decreasing.
- I_{sc} is the instability in velocity maintenance. It is an estimate of the extent of the velocity fluctuations that occur when the driver is attempting to maintain a chosen velocity.

APPENDIX 7: ANOVA SUMMARY TABLES

Appendix 7 contains the full summary tables for the eight ANOVA's conducted on the lane-keeping and velocity-maintenance performance measures. They are presented on the following pages in the same order in which they were discussed in section 3 of the main report.

Table 43. The ANOVA conducted to determine if average velocity was affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	17.372903	17.372903	3.41	0.0718
Age (A)	1	120.205402	120.205402	23.58	0.0001
G x A	1	1.397976	1.397976	0.27	0.6032
Density (D)	1	5.780741	5.780741	1.13	0.2928
D x G	1	0.093846	0.093846	0.02	0.8927
D x A	1	1.599087	1.599087	0.31	0.5783
D x A x G	1	0.519994	0.519994	0.10	0.7510
S (w/ A x G x D)	43	219.168298	5.096937		
Visibility (V)	2	547.585163	273.792581	378.63	0.0001
V x G	2	0.007137	0.003569	0.00	0.9951
V x A	2	4.015944	2.007972	2.78	0.0680
V x A x G	2	1.735078	0.8675389	1.20	0.3064
D x V	2	2.606461	1.303230	1.80	0.1712
D x V x G	2	0.510637	0.255318	0.35	0.7036
D x V x A	2	1.793876	0.896938	1.24	0.2945
D x V x G x A	2	0.311801	0.155900	0.22	0.8065
V x S (w/ A x G x D)	84	60.741492	0.723113		

Table 44. The ANOVA conducted to determine if the minimum following distance (in seconds) was affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	1.457712	1.457712	0.48	0.4934
Age (A)	1	64.625963	64.625963	21.16	0.0001
G x A	1	3.646283	3.646283	1.19	0.2807
Density (D)	1	6.848698	6.848698	2.24	0.1416
D x G	1	5.192466	5.192466	1.70	0.1992
D x A	1	2.953424	2.953424	0.97	0.3309
D x A x G	1	5.729051	5.729051	1.88	0.1779
S (w/ A x G x D)	43	131.339056	3.054397		
Visibility (V)	2	2.256260	1.128130	0.94	0.3964
V x G	2	6.035346	3.017673	2.50	0.0881
V x A	2	3.640435	1.820217	1.51	0.2270
V x A x G	2	9.388835	4.694417	3.89	0.0243
D x V	2	0.140094	0.070047	0.06	0.9436
D x V x G	2	4.904254	2.452127	2.03	0.1374
D x V x A	2	2.235174	1.117587	0.93	0.3998
D x V x G x A	2	1.811926	0.905963	0.75	0.4748
V x S (w/ A x G x D)	81	97.626480	1.205265		

Table 45. The ANOVA conducted to determine if the average actual gap was affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	5.4935784	5.4935784	4.97	0.0311
Age (A)	1	14.6669445	14.6669445	13.26	0.0007
G x A	1	0.5724932	0.5724932	0.52	0.4757
Density (D)	1	0.4778618	0.4778618	0.43	0.5144
D x G	1	0.0275126	0.0275126	0.02	0.8754
D x A	1	0.8432229	0.8432229	0.76	0.3874
D x A x G	1	0.0920512	0.0920512	0.08	0.7743
S (w/ A x G x D)	43	47.5452271	1.1057030		
Visibility (V)	2	0.3019548	0.1509774	0.34	0.7154
V x G	2	1.2216514	0.6108257	1.36	0.2623
V x A	2	0.0620910	0.0310455	0.07	0.9332
V x A x G	2	0.3944525	0.1972263	0.44	0.6460
D x V	2	0.9180103	0.4590051	1.02	0.3643
D x V x G	2	0.3309323	0.1654661	0.37	0.6929
D x V x A	2	0.6029154	0.3014577	0.67	0.5138
D x V x G x A	2	0.9730579	0.4865290	1.08	0.3432
V x S (w/ A x G x D)	81	36.3631881	0.4489282		

Table 46. The ANOVA conducted to determine if the average gap setting was affected by group—whether the driver was in the experimental group (when the SSGCS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	0.7309536	0.7309536	0.34	0.5644
Age (A)	1	22.4407808	22.4407808	10.35	0.0025
G x A	1	0.0187384	0.0187384	0.01	0.9263
Density (D)	1	3.8786784	3.8786784	1.79	0.1880
D x G	1	2.0339382	2.0339382	0.94	0.3381
D x A	1	0.0003391	0.0003391	0.00	0.9901
D x A x G	1	1.3834100	1.3834100	0.64	0.4287
S (w/ A x G x D)	43	93.1932122	2.1672840		
Visibility (V)	2	0.6533215	0.3266607	0.78	0.4622
V x G	2	0.3859558	0.1929779	0.46	0.6328
V x A	2	0.0282547	0.0141273	0.03	0.9669
V x A x G	2	0.7628940	0.3814470	0.91	0.4067
D x V	2	0.7576016	0.3788008	0.90	0.4092
D x V x G	2	0.2324912	0.1162456	0.28	0.7586
D x V x A	2	0.2600702	0.1300351	0.31	0.7342
D x V x G x A	2	0.5150447	0.2575223	0.61	0.5436
V x S (w/ A x G x D)	81	33.9617913	0.4192814		

Table 47. The ANOVA conducted to determine if steering instability was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	0.04987882	0.04987882	4.63	0.0381
Age (A)	1	0.01435652	0.01435652	1.33	0.2558
G x A	1	0.00504152	0.00504152	0.47	0.4983
Density (D)	1	0.05734351	0.05734351	5.32	0.0268
D x G	1	0.00157931	0.00157931	0.15	0.7041
D x A	1	0.00000381	0.00000381	0.00	0.9851
D x A x G	1	0.00019790	0.00019790	0.02	0.8929
S (w/ A x G x D)	37	0.39877310	0.01077765		
Visibility (V)	2	0.00439144	0.00219572	0.86	0.4281
V x G	2	0.00262457	0.00131228	0.51	0.6005
V x A	2	0.00629897	0.00314948	1.23	0.2984
V x A x G	2	0.00466973	0.00233487	0.92	0.4060
D x V	2	0.00024579	0.00012290	0.05	0.9530
D x V x G	2	0.00864802	0.00432401	1.70	0.1925
D x V x A	2	0.00590125	0.00295063	1.16	0.3216
D x V x G x A	2	0.00336730	0.00168365	0.66	0.5206
V x S (w/ A x G x D)	58	0.14792475	0.00255043		

Table 48. The ANOVA conducted to determine if the number of steering oscillations/min were affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	1256.28728	1256.28728	43.89	0.0001
Age (A)	1	15.04787	15.04787	0.53	0.4730
G x A	1	117.87201	117.87201	4.12	0.0497
Density (D)	1	4.29795	4.29795	0.15	0.7006
D x G	1	1.83603	1.83603	0.06	0.8015
D x A	1	0.82566	0.82566	0.03	0.8661
D x A x G	1	31.63401	31.63401	1.11	0.3000
S (w/ A x G x D)	37	1059.06713	28.62344		
Visibility (V)	2	214.13589	107.06794	10.85	0.0001
V x G	2	117.77033	58.88516	5.97	0.0044
V x A	2	62.55992	31.27996	3.17	0.0492
V x A x G	2	79.85840	39.92920	4.05	0.0225
D x V	2	23.14491	11.57246	1.17	0.3165
D x V x G	2	27.10368	13.55184	1.37	0.2611
D x V x A	2	4.47462	2.23731	0.23	0.7978
D x V x G x A	2	67.37304	33.68652	3.41	0.0395
V x S (w/ A x G x D)	59	581.99654	9.86435		

Table 49. The ANOVA conducted to determine if the average velocity was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	7.255068	7.255068	1.25	0.2699
Age (A)	1	115.876738	115.876738	20.04	0.0001
G x A	1	0.109023	0.109023	0.02	0.8915
Density (D)	1	6.167485	6.167485	1.07	0.3085
D x G	1	0.027364	0.027364	0.00	0.9455
D x A	1	6.209395	6.209395	1.07	0.3068
D x A x G	1	0.612591	0.612591	0.11	0.7467
S (w/ A x G x D)	37	213.987099	5.783435		
Visibility (V)	2	334.829328	167.414664	289.13	0.0001
V x G	2	4.526930	2.263465	3.91	0.0254
V x A	2	7.625705	3.812852	6.58	0.0026
V x A x G	2	2.295161	1.147581	1.98	0.1467
D x V	2	3.662095	1.831048	3.16	0.0495
D x V x G	2	1.643324	0.821662	1.42	0.2499
D x V x A	2	0.123408	0.061704	0.11	0.8991
D x V x G x A	2	1.079960	0.539980	0.93	0.3992
V x S (w/ A x G x D)	60	34.741536	0.579026		

Table 50. The ANOVA conducted to determine if the velocity instability was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	13.1808974	13.1808974	51.49	0.0001
Age (A)	1	0.0281315	0.0281315	0.11	0.7421
G x A	1	0.0088072	0.0088072	0.03	0.8539
Density (D)	1	0.0001257	0.0001257	0.00	0.9824
D x G	1	0.1671248	0.1671248	0.65	0.4243
D x A	1	0.0877755	0.0877755	0.34	0.5617
D x A x G	1	0.1737210	0.1737210	0.68	0.4153
S (w/ A x G x D)	37	9.4714475	0.2559851		
Visibility (V)	2	0.1423154	0.0711577	0.63	0.5337
V x G	2	0.9654707	0.4827353	4.31	0.0179
V x A	2	0.1736361	0.0868181	0.77	0.4656
V x A x G	2	1.1396384	0.5698192	5.08	0.0091
D x V	2	0.5841212	0.2920606	2.60	0.0823
D x V x G	2	0.2030614	0.1015307	0.91	0.4098
D x V x A	2	0.2644329	0.1322164	1.18	0.3146
D x V x G x A	2	0.1646264	0.0823132	0.73	0.4842
V x S (w/ A x G x D)	60	6.7279470	0.1121324		

Table 51. The ANOVA conducted to determine if the number of velocity fluctuations was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	3137.03975	3137.03975	63.20	0.0001
Age (A)	1	20.83980	20.83980	0.42	0.5210
G x A	1	84.36627	84.36627	1.70	0.2004
Density (D)	1	30.24884	30.24884	0.61	0.4400
D x G	1	28.07274	28.07274	0.57	0.4568
D x A	1	1.72388	1.72388	0.03	0.8532
D x A x G	1	2.47876	2.47876	0.05	0.8244
S (w/ A x G x D)	37	1836.60034	49.63785		
Visibility (V)	2	3.87886	1.93943	0.10	0.9066
V x G	2	2.85519	1.42759	0.07	0.9304
V x A	2	125.04900	62.52450	3.16	0.0496
V x A x G	2	136.69280	68.34640	3.46	0.0381
D x V	2	94.09232	47.04616	2.38	0.1014
D x V x G	2	127.31727	63.65863	3.22	0.0471
D x V x A	2	166.06309	83.03154	4.20	0.0197
D x V x G x A	2	159.24014	79.62007	4.03	0.0230
V x S (w/ A x G x D)	58	1145.81513	19.75543		

Table 52. The ANOVA conducted to determine if the minimum following distance (in meters) was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	0.6574	0.6574	0.00	0.9757
Age (A)	1	8027.7871	8027.7871	11.45	0.0018
G x A	1	2247.7070	2247.7070	3.21	0.0820
Density (D)	1	5715.2760	5715.2760	8.15	0.0072
D x G	1	333.1561	333.1561	0.48	0.4952
D x A	1	718.5606	718.5606	1.02	0.3183
D x A x G	1	342.2983	342.2983	0.49	0.4893
S (w/ A x G x D)	35	24539.2262	701.1207		
Visibility (V)	2	3744.2053	1872.1027	5.73	0.0058
V x G	2	558.3233	279.1616	0.85	0.4316
V x A	2	4531.1515	2265.5758	6.94	0.0022
V x A x G	2	16.8260	8.4130	0.03	0.9746
D x V	2	82.3767	41.1883	0.13	0.8818
D x V x G	2	515.6386	257.8193	0.79	0.4598
D x V x A	2	2119.6504	1059.8252	3.25	0.0475
D x V x G x A	2	587.6189	293.8095	0.90	0.4133
V x S (w/ A x G x D)	49	16002.1032	326.5735		

Table 53. The ANOVA conducted to determine if the average actual gap was affected by group—whether the driver was in the experimental group (when only the CWS was being used) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	2.5603545	2.5603545	2.23	0.1441
Age (A)	1	11.5484117	11.5484117	10.06	0.0031
G x A	1	0.3220493	0.3220493	0.28	0.5996
Density (D)	1	2.9296638	2.9296638	2.55	0.1189
D x G	1	1.6098531	1.6098531	1.40	0.2441
D x A	1	0.8434683	0.8434683	0.73	0.3971
D x A x G	1	0.0191118	0.0191118	0.02	0.8981
S (w/ A x G x D)	36	41.3374278	1.1482619		
Visibility (V)	2	0.4135003	0.2067502	0.42	0.6619
V x G	2	0.3111279	0.1555640	0.31	0.7327
V x A	2	0.5793989	0.2896994	0.58	0.5618
V x A x G	2	0.2304163	0.1152082	0.23	0.7940
D x V	2	0.1629383	0.0814692	0.16	0.8493
D x V x G	2	0.4582332	0.2291166	0.46	0.6332
D x V x A	2	0.9981029	0.4990514	1.00	0.3730
D x V x G x A	2	1.4110153	0.7055077	1.42	0.2504
V x S (w/ A x G x D)	58	28.8546553	0.4974941		

Table 54. The ANOVA conducted to determine if steering instability was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	0.04697795	0.04697795	5.31	0.0269
Age (A)	1	0.01289196	0.01289196	1.46	0.2351
G x A	1	0.00105782	0.00105782	0.12	0.7315
Density (D)	1	0.00846733	0.00846733	0.96	0.3343
D x G	1	0.01459340	0.01459340	1.65	0.2071
D x A	1	0.00798987	0.00798987	0.90	0.3482
D x A x G	1	0.00660883	0.00660883	0.75	0.3931
S (w/ A x G x D)	37	0.32743927	0.00884971		
Visibility (V)	2	0.00021176	0.00010588	0.04	0.9590
V x G	2	0.00212797	0.00106399	0.42	0.6595
V x A	2	0.00302274	0.00151137	0.60	0.5551
V x A x G	2	0.02566789	0.01283394	5.08	0.0111
D x V	2	0.00003179	0.00001590	0.01	0.9937
D x V x G	2	0.00484456	0.00242228	0.96	0.3927
D x V x A	2	0.00010911	0.00005456	0.02	0.9787
D x V x G x A	2	0.00527032	0.00263516	1.04	0.3625
V x S (w/ A x G x D)	38	0.09608113	0.00252845		

Table 55. The ANOVA conducted to determine if the number of steering oscillations/min were affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	906.965298	906.965298	75.60	0.0001
Age (A)	1	22.531485	22.531485	1.88	0.1793
G x A	1	97.648718	97.648718	8.14	0.0072
Density (D)	1	38.067678	38.067678	3.17	0.0835
D x G	1	31.674074	31.674074	2.64	0.1132
D x A	1	27.888671	27.888671	2.32	0.1363
D x A x G	1	75.942796	75.942796	6.33	0.0166
S (w/ A x G x D)	35	419.876340	11.996467		
Visibility (V)	2	150.521683	75.260842	18.75	0.0001
V x G	2	16.560468	8.280234	2.06	0.1418
V x A	2	49.339075	24.669538	6.15	0.0050
V x A x G	2	50.452007	25.226004	6.29	0.0046
D x V	2	3.912726	1.956363	0.49	0.6182
D x V x G	2	2.707522	1.353761	0.34	0.7159
D x V x A	2	28.451176	14.225588	3.54	0.0393
D x V x G x A	1	2.763203	1.381601	0.34	0.7110
V x S (w/ A x G x D)	36	144.470425	4.013067		

Table 56. The ANOVA conducted to determine if the average velocity was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	0.487470	0.487470	0.07	0.7894
Age (A)	1	79.103969	79.103969	11.74	0.0015
G x A	1	0.929216	0.929216	0.14	0.7124
Density (D)	1	4.373273	4.373273	0.65	0.4255
D x G	1	0.094866	0.094866	0.01	0.9062
D x A	1	0.140148	0.140148	0.02	0.8861
D x A x G	1	1.025474	1.025474	0.15	0.6986
S (w/ A x G x D)	37	249.228133	6.735895		
Visibility (V)	2	187.331468	93.665734	118.83	0.0001
V x G	2	3.115006	1.557503	1.98	0.1526
V x A	2	2.938561	1.469280	1.86	0.1689
V x A x G	2	1.107256	0.553628	0.70	0.5017
D x V	2	2.918066	1.459033	1.85	0.1710
D x V x G	2	5.715056	2.857528	3.63	0.0362
D x V x A	2	1.440340	0.720170	0.91	0.4097
D x V x G x A	2	2.499306	1.249653	1.59	0.2181
V x S (w/ A x G x D)	38	29.952515	0.788224		

Table 57. The ANOVA conducted to determine if the velocity instability was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	10.8559986	10.8559986	41.12	0.0001
Age (A)	1	0.1029537	0.1029537	0.39	0.5362
G x A	1	0.1488575	0.1488575	0.56	0.4575
Density (D)	1	0.0034329	0.0034329	0.01	0.9098
D x G	1	0.1427672	0.1427672	0.54	0.4668
D x A	1	0.0297818	0.0297818	0.11	0.7389
D x A x G	1	0.1585509	0.1585509	0.60	0.4433
S (w/ A x G x D)	37	9.7683887	0.2640105		
Visibility (V)	2	0.5055148	0.2527574	1.53	0.2290
V x G	2	0.4865199	0.2432599	1.47	0.2416
V x A	2	0.3036209	0.1518104	0.92	0.4070
V x A x G	2	0.5812747	0.2906374	1.76	0.1854
D x V	2	0.2047127	0.1023563	0.62	0.5430
D x V x G	2	0.5687270	0.2843635	1.72	0.1920
D x V x A	2	0.0533787	0.0266893	0.16	0.8512
D x V x G x A	2	0.3037004	0.1518502	0.92	0.4069
V x S (w/ A x G x D)	38	6.2671642	0.1649254		

Table 58. The ANOVA conducted to determine if the number of velocity fluctuations was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	1809.29672	1809.29672	24.41	0.0001
Age (A)	1	162.64355	162.64355	2.19	0.1475
G x A	1	254.47126	254.47126	3.43	0.0723
Density (D)	1	89.61962	89.61962	1.21	0.2790
D x G	1	86.69624	86.69624	1.17	0.2869
D x A	1	20.68803	20.68803	0.28	0.6006
D x A x G	1	24.32560	24.32560	0.33	0.5704
S (w/ A x G x D)	35	2594.06512	74.11615		
Visibility (V)	2	45.91350	22.95675	17.24	0.0001
V x G	2	28.20996	14.10498	10.59	0.0002
V x A	2	16.61116	8.30558	6.24	0.0046
V x A x G	2	17.02897	8.51449	6.39	0.0041
D x V	2	16.22153	8.11076	6.09	0.0052
D x V x G	2	12.63905	6.31953	4.75	0.0146
D x V x A	2	34.08150	17.04075	12.80	0.0001
D x V x G x A	1	48.81588	48.81588	36.66	0.0001
V x S (w/ A x G x D)	37	49.27518	1.33176		

Table 59. The ANOVA conducted to determine if the minimum following distance (in meters) was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	1636.7172	1636.7172	2.41	0.1330
Age (A)	1	3989.2997	3989.2997	5.86	0.0227
G x A	1	2099.3885	2099.3885	3.09	0.0908
Density (D)	1	208.4740	208.4740	0.31	0.5846
D x G	1	867.9448	867.9448	1.28	0.2690
D x A	1	0.0864	0.0864	0.00	0.9911
D x A x G	1	1615.9428	1615.9428	2.38	0.1354
S (w/ A x G x D)	26	17689.0061	680.3464		
Visibility (V)	2	3324.5938	1662.2969	5.75	0.0081
V x G	2	512.4505	256.2253	0.89	0.4233
V x A	2	2736.2175	1368.1088	4.73	0.0169
V x A x G	0	0.0000	-	-	-
D x V	2	1009.3426	504.6713	1.75	0.1929
D x V x G	1	602.3138	602.3138	2.08	0.1599
D x V x A	2	359.9440	179.9720	0.62	0.5437
D x V x G x A	0	0.0000	-	-	-
V x S (w/ A x G x D)	28	8091.1096	288.9682		

Table 60. The ANOVA conducted to determine if the average actual gap was affected by group—whether the driver was in the experimental group (when both the SSGCS and the CWS were disengaged) or the control group—the age of the driver, the density of traffic, or the level of visibility.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	*p*
Group (G)	1	0.6494415	0.6494415	0.63	0.4324
Age (A)	1	16.187230	16.187230	15.71	0.0003
G x A	1	1.0305836	1.0305836	1.00	0.3238
Density (D)	1	0.0042700	0.0042700	0.00	0.9490
D x G	1	0.0852388	0.0852388	0.08	0.7753
D x A	1	0.0127410	0.0127410	0.01	0.9121
D x A x G	1	0.9288284	0.9288284	0.90	0.3486
S (w/ A x G x D)	37	38.1359029	1.0307001		
Visibility (V)	2	6.9772624	3.4886312	6.92	0.0030
V x G	2	4.5511117	2.2755558	4.51	0.0182
V x A	2	3.3242315	1.6621157	3.30	0.0491
V x A x G	2	5.7277787	2.8638893	5.68	0.0074
D x V	2	1.8530696	0.9265348	1.84	0.1746
D x V x G	2	1.7659544	0.8829772	1.75	0.1888
D x V x A	2	1.1426171	0.5713085	1.13	0.3338
D x V x G x A	2	0.6585024	0.3292512	0.65	0.5268
V x S (w/ A x G x D)	34	17.1384355	0.5040716		

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