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 combined experiments were: (1) to determine whether driving behavior would be affected by traveling for an extended period of time under automated control at a speed greater than the speed limit and with a much-shorter-than-usual distance between the driver's car and the vehicle immediately ahead, (2) to determine the effect on the driver's post-AHS behavior of varying the distance between the driver's car and the vehicle immediately ahead while the driver was traveling in the automated lane for an extended period of time, and (3) to determine the effect on the driver's post-AHS behavior of varying the method of transferring control from the AHS back to the driver as his/her vehicle left the automated lane. To achieve these objectives, driving-performance data were obtained before and after each driver traveled under automated control in the automated lane for an extended period of time. The analyses of these data focused on the following experimental questions.

- *Does traveling under automated control for an extended period of time have an immediate effect on post-AHS driving performance?*
- *Does traveling under automated control for an extended period of time have a prolonged effect on post-AHS driving performance?*
- *Does the age of the driver affect the driver's performance after he/she has traveled under automated control for an extended period of time?*
- *Does the method of transferring control back to the driver after he/she has traveled in the automated lane for an extended period of time affect post-AHS driving performance?*
- *Does the intra-string gap experienced by the driver while traveling in the automated lane for an extended period of time affect post-AHS driving performance?*

DATA ANALYSIS

To answer these questions, driving-performance data were obtained from 48 drivers who traveled on a simulated journey of approximately 1 h. For the 36 drivers who were in the experimental groups, the journey was divided into three sections: a pre-AHS, an AHS, and a post-AHS section. Pre-AHS driving-performance data were collected from these drivers from the beginning of the sixth minute until 14.5 min after the start of the trial, at which point the AHS issued a message requesting the driver to move into or stay in the center lane. Post-AHS driving-performance data were collected from the time that complete control of the simulator vehicle had been transferred back to the driver until the end of the trial, approximately 9 min later.

The remaining 12 drivers were in the control group. They retained control of the vehicle throughout the journey. Driving-performance data were collected from these drivers in two data-collection periods that occurred early and late in the trial: the early data-collection period started at the beginning of the 6th minute and finished at the end of the 50th minute of the trial, while the late data-collection period started at the beginning of the 51st minute and lasted until the end of the 59th minute.

Thirteen driving measures were collected from the drivers in the control and experimental groups during the two data-collection periods early and late in the trial. These measures are listed in table 5.

Because little is known about the effects on manual driving behavior of traveling under automated control, particularly after automated travel as long as that used in this experiment, it was believed that a fine-grained look at the data was the best approach. Consequently, the post-automated travel data (i.e., in the late data-collection period) were segmented into nine successive 1-min periods to provide an opportunity to catch both immediate-but-short-lived effects and more persistent effects. This segmentation scheme was used with the first six driving measures shown in table 5: the two lane-keeping measures and the four speed-control measures. Because for some measures a 1-min period would either produce no data or too little data to be meaningful, the segmentation scheme was not used with the other measures in table 5: minimum following distance, percentage of time in the right and center lanes, number of lane changes, minimum gap size accepted in a lane change, number of incursions, and size of gap rejected in an incursion.

Five of the six driving measures for which the segmentation scheme was appropriate were developed recently. Bloomfield and Carroll suggest that the driver's lane-keeping performance can be described in terms of a linear equation that is the line of best fit for a series of points along the track of a vehicle.(14) This equation describes the position of a vehicle relative to the center of the lane at any time. The two lane-keeping measures listed in table 5 are measures of the driver's steering ability that are derived from this equation. The *steering instability* is a measure of the variability in steering that occurs when the driver is maintaining his/her position in the lane. Mathematically, it is the variability (i.e., the residual standard deviation) of the track of the vehicle about the line of best fit. *Steering oscillations* occur whenever the track of the vehicle crosses the line of best fit. The frequency with which steering oscillations occur is measured by determining the number of times that the track of the vehicle crosses the line of best fit per minute.

Table 5. Driving-performance measures collected in the pre-AHS and post-AHS sections of the trial.

Lane-keeping measures	• Steering instability.[1] • Number of steering oscillations.[1]
Speed-control measures	• Average velocity. • Velocity drift.[1] • Velocity instability.[1] • Number of velocity fluctuations.[1]
Following-distance measure	Minimum following distance
Lane-change measures	• Percentage of time spent in the center lane. • Percentage of time spent in the right lane. • Number of lane changes. • Size of gap accepted in a lane change.
Incursion measures	• Number of incursions. • Size of gap rejected in a lane incursion.

[1] Driving-performance measures developed by Bloomfield and Carroll.(14) [A brief account describing the development of these measures is provided in appendix 5.]

Bloomfield and Carroll also suggest that the driver's ability to control the speed of his/her vehicle can be described using another linear equation that is the line of best fit for speed control.(14) Three of the four speed control measures listed in table 5 are derived from this equation. The *velocity drift* is a measure of the rate at which the velocity of the vehicle increases or decreases as a function of the distance traveled along the lane. It is the gradient of the line of best fit of the actual velocities of the vehicle (measured in this experiment) every one-thirtieth of a second. The *velocity instability* measures the variability in velocity that occurs when the driver is driving along the lane. Mathematically, it is the variability (i.e., the residual standard deviation) of the actual velocities of the vehicle about the line of best fit. *Velocity fluctuations* occur every time the plot of the actual velocities of the vehicle crosses the line of best fit. The frequency with which velocity fluctuations occur is measured by determining the number of times per minute that the line of best fit is crossed. [Further details of the derivation of these measures are presented in appendix 5.]

Average velocity, the fourth speed-control measure in table 5, gives an overall indication of the driver's speed. The remaining seven measures listed in table 5 are self-explanatory.

As noted above, two different analyses of variance (ANOVA's) were done on the dependent variables, each collapsing across one of the independent variables. The independent measures used in each analysis and their levels are shown in table 6. Note importantly that the control-group data are used as one of the levels of one of the independent variables in each analysis.

Table 6. Independent variables used in the two ANOVA's and their levels.

Independent Variable	Levels
Intra-String Gap Analysis (collapsed across control transfer methods)	
Age	25 through 34, 65 and older
Data-collection period	Early, late
Intra-string gap	0.0344 s, 0.0625 s, control group
Transfer-Method Analysis (collapsed across intra-string gaps)	
Age	25 through 34, 65 and older
Data-collection period	Early, late
Transfer method	Speed first, steering first, speed and steering simultaneously, control group

LANE-KEEPING PERFORMANCE

Two lane-keeping measures, the steering instability and the number of steering oscillations, are discussed in this section. Four ANOVA's were conducted: two for the steering instability and two for the number of steering oscillations. For both variables, the first ANOVA determined the effect on the driver's post-AHS driving performance of varying the intra-string gap. For this analysis, the data were collapsed over the methods of transferring control. The second ANOVA analyzed the effect of varying the method of transferring control, this time collapsing the data over the intra-string gaps. In both ANOVA's, data averaged over the entire early data-collection period were compared with data from each of the nine 1-min segments into which the late data-collection period was divided.

Steering Instability

The steering instability provides a measure of the variability in steering around the line of best fit of the track of the vehicle. The statistically significant effects found by the two ANOVA's conducted on these data are shown in table 7. The complete summary tables for these ANOVA's are presented in appendix 7.

Table 7. Summary of the statistically significant effects found in the ANOVA's conducted to determine if the steering instability or number of steering oscillations were affected by the data-collection period (D), the age of the driver, the intra-string gap (I), or the method of transferring control.

	Steering Instability		Number of Steering Oscillations	
Source	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]
D	0.0002	0.0001	–	–
I x D	0.0372	–	–	–

[a] Control group is one level of intra-string gap.

[b] Control group is one level of transfer method.

As can be seen from table 7, only one variable—the difference between the early and late data-collection periods—had a statistically significant effect. The other three independent variables did not produce significant differences. It should be noted that, since neither the intra-string gap nor the method of control transfer had a statistically significant effect, there was no evidence of a difference between the steering instability for the drivers in the experimental groups and the steering instability of the drivers in the control group. There was one statistically significant interaction, that between data-collection period and the intra-string gap.

Interaction Between Data-collection period and Intra-String Gap. The summary of the intra-string gap ANOVA, shown in table 7, reveals that there was a statistically significant interaction between data-collection period and intra-string gap. This interaction is illustrated in figure 2. It occurred because there was more steering instability for the drivers in the control group in four of

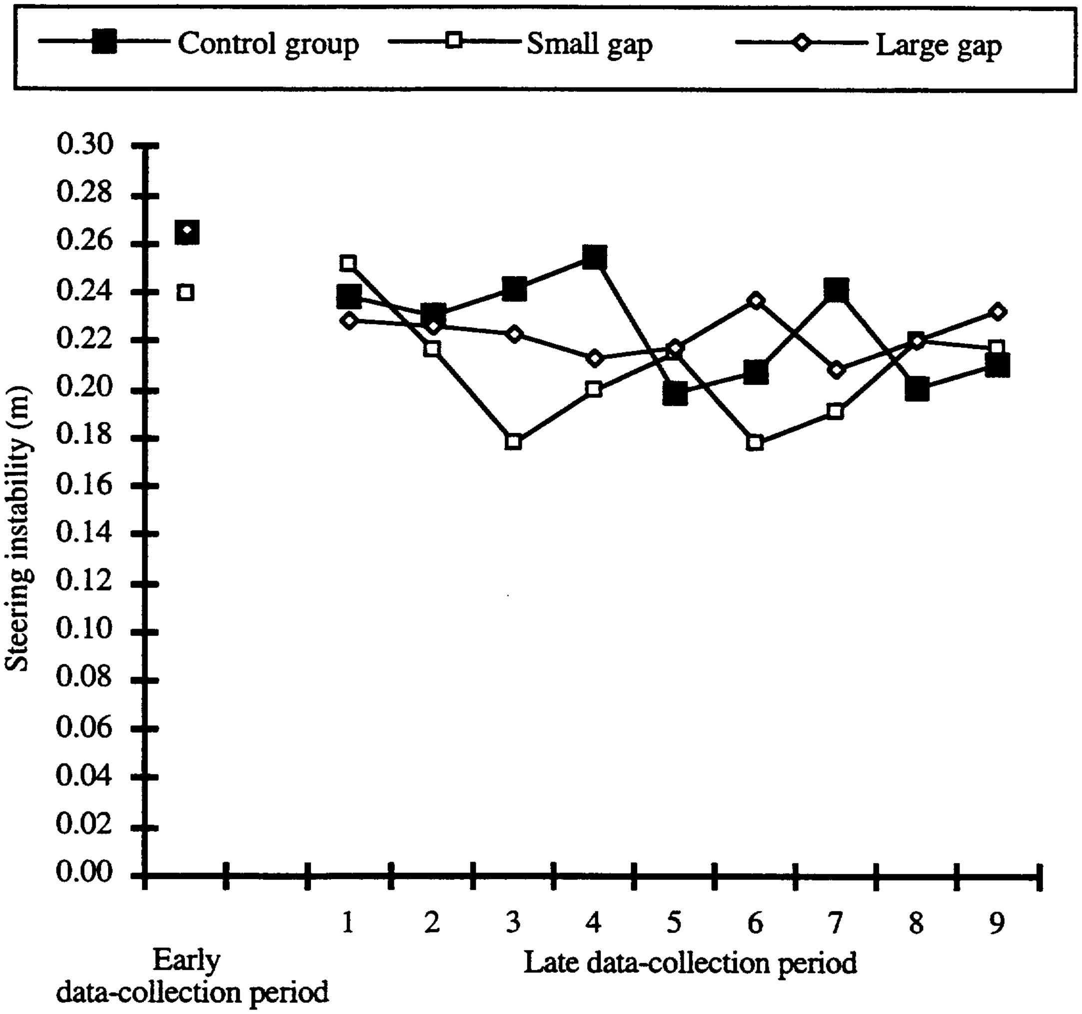

Figure 2. Comparisons of the mean steering instabilities in the early data-collection period and the nine 1-min segments in the late data-collection period of the drivers in the control group and the drivers in the small- and large-intra-string-gap groups.

the nine 1-min segments of the late data-collection period (the second, third, fourth, and seventh segments), more steering instability for the drivers who traveled under automated control with the large (0.0625-s) intra-string gap in four of the nine 1-min segments of the late data-collection period (the fifth, sixth, eighth, and ninth segments), and more steering instability for the drivers who traveled under automated control with the small (0.0344-s) intra-string gap in only one of the 1-min segments of the late data-collection period (the first segment).

<u>Data-collection period.</u> As can be seen in table 7, the summaries of the intra-string gap ANOVA and the transfer-method ANOVA both indicate that there were statistically significant differences in the steering instability means obtained in the early and late data-collection periods. [Note: Since the two ANOVA's analyzed the same data—one collapsing across transfer methods, the other across intra-string gaps—the steering instability means obtained in the early and late data-collection periods were the same in both ANOVA's.] The Tukey Studentized Range test was used to determine which steering instability means were significantly different; the results are shown in table 8.

As the first line in table 8 indicates, the mean steering instability in the early data-collection period was significantly different from the steering instability in seven of the nine 1-min segments of the late data-collection period (the exceptions were the first two 1-min segments of the late period). The table also shows that the mean steering instability in the first 1-min segment of the late period was significantly different from the steering instability in the sixth 1-min segment of the late data-collection period. These significant differences are illustrated in figure 3, which also shows that there was an overall decrease in steering instability from the early to the late data-collection period. To determine whether this decrease occurred for the drivers in the control and the experimental groups, it was first necessary to average the data for the drivers in the experimental groups over both the intra-string gap and the method of control transfer. Then, the drivers in the control and experimental groups were compared. The results are shown in figure 4.

Table 8. Results of all pairwise comparisons of average steering instability between the early data-collection period and each 1-min segment of the late data-collection period.[a]

		1-min Segment of the Late Data-Collection Period								
	Early Data-Collection Period	1	2	3	4	5	6	7	8	9
Early Data-Collection Period		–	–	*	*	*	*	*	*	*
1			–	–	–	–	*	–	–	–
2				–	–	–	–	–	–	–
3					–	–	–	–	–	–
4						–	–	–	–	–
5							–	–	–	–
6								–	–	–
7									–	–
8										–
9										

[a] "–" means the comparison was not significant; "*" means the comparison was significant at $p \leq 0.05$. Thus, the "-" at the intersection of "early data-collection period" and "1" indicates that there was no significant difference between pre-AHS average steering instability ("early data-collection period") and average steering instability in the first minute post-AHS ("1").

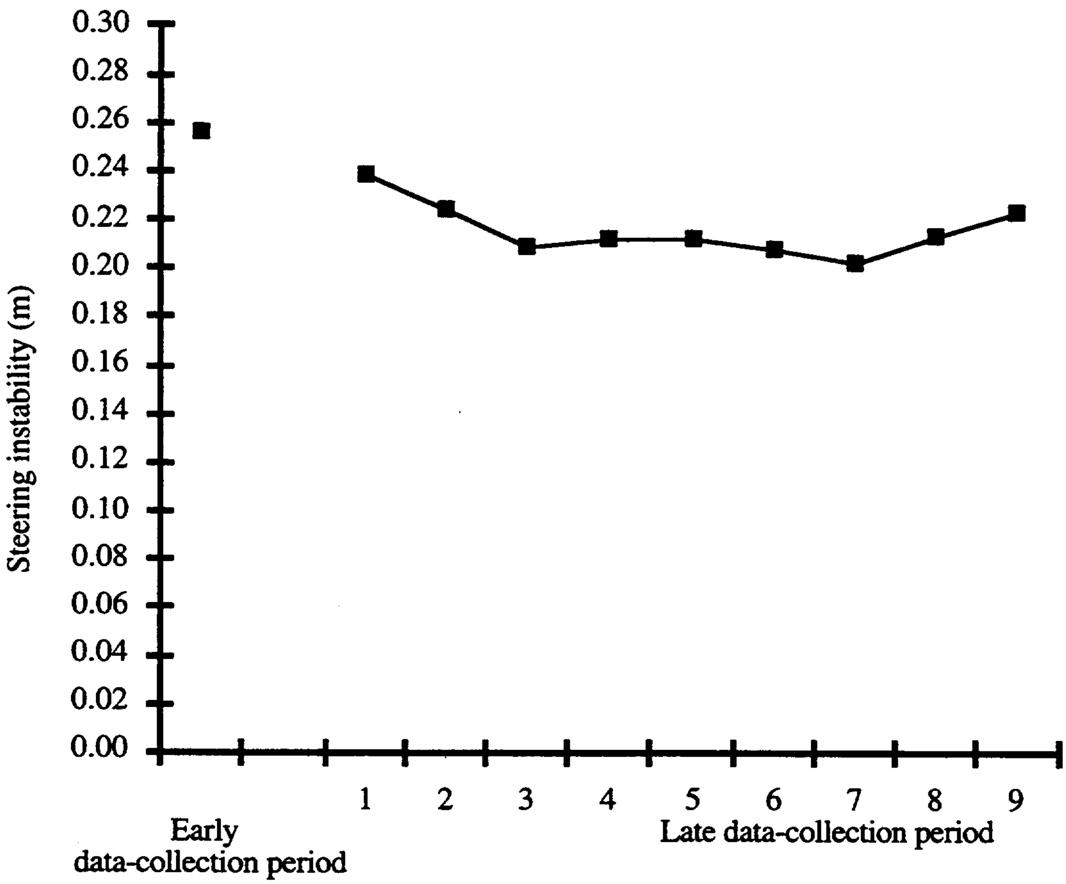

Figure 3. The mean steering instability in the early data-collection period compared with the mean steering instability in each of the nine 1-min segments in the late data-collection period.

Figure 4 confirms that the decrease in steering instability from the early to the late data-collection period occurred for the drivers in both the control and experimental groups. In addition, the figure illustrates—as can be inferred from the lack of a statistically significant difference (in table 7) in the steering instability means of the drivers in the control and experimental groups—that there was little difference in steering instability of the drivers in the control and experimental groups.

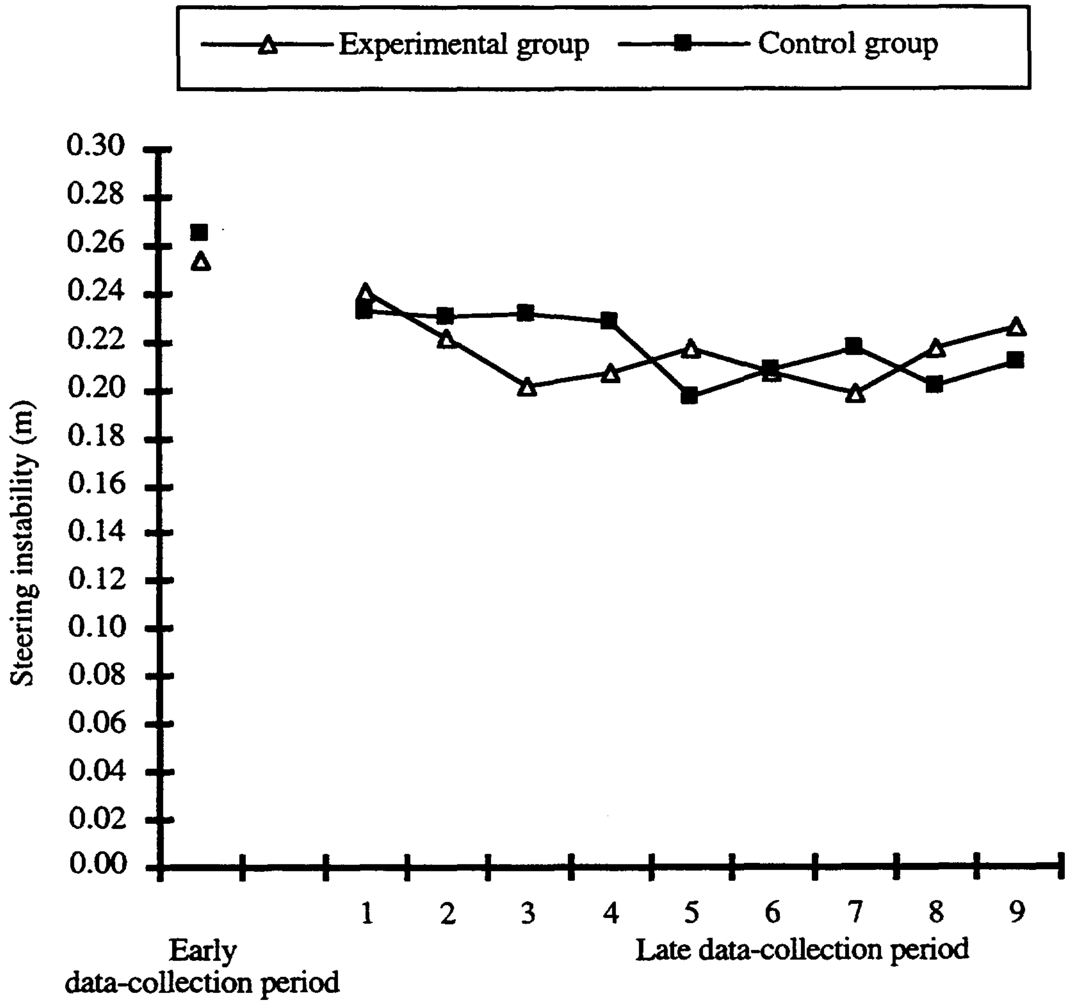

Figure 4. The mean steering instability in the early data-collection period compared with the mean steering instability in each of the nine 1-min segments in the late data-collection period for the drivers in both the control and experimental groups.

Number Of Steering Oscillations

Table 7 indicates that no statistically significant differences were found in the two ANOVA's that were conducted to determine whether the number of steering oscillations (i.e., the number of times the steering line of best fit was crossed per minute) was affected by which data period the data were collected in, the age of the driver, the intra-string gap, or the method of control transfer. The average number of steering oscillations across all variables was 13.3.

SPEED-CONTROL PERFORMANCE

The four speed-control measures investigated were the velocity drift, the velocity instability, the number of velocity fluctuations, and the average velocity. Two ANOVA's were conducted to determine whether these speed-control measures were affected by the data-collection period, the age of the driver, the intra-string gap, or the method of transferring control. The variables that were found to have statistically significant effects on the speed-control measures are listed in table 9. The complete summary tables for these eight ANOVA's are presented in appendix 7. As table 9 shows, there were no statistically significant interactions in any of the eight ANOVA's.

Table 9. Summary of the statistically significant effects found in the ANOVA's conducted to determine if the speed-control measures were affected by the data-collection period (D), the age of the driver (A), the intra-string gap, or by the method of transferring control.

	Average Velocity		Velocity Drift		Velocity Instability		Number of Velocity Fluctuations	
Source	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]
A	0.0160	0.0157	–	–	–	–	–	–
D	–	–	–	–	0.0001	0.0001	0.0001	0.0001

[a] Control group is one level of intra-string gap.

[b] Control group is one level of transfer method.

Both sets of analyses were conducted on the speed-control measures in order to determine whether the measures were affected by the data-collection period or by the age of the driver. In addition, the first analysis in each pair of ANOVA's indicated whether any of the four speed-control measures were affected by variations in the size of the intra-string gap, with the data collapsed over the methods of transferring control. The second analysis in each pair indicated whether the speed-control measures were affected by variations in the method of transferring control, with the data collapsed over the intra-string gaps.

As can be seen from table 9, the age of the driver had a statistically significant effect on the average velocity. However, the table also shows that no statistically significant effects were found for the velocity drift. For the remaining two speed-control measures, the velocity instability and the number of velocity fluctuations, statistically significant differences were found between the early and late data-collection periods. In addition, it should be noted that neither the intra-string gap nor the method of control transfer had a statistically significant effect on any of the four speed control measures. So, as with the lane-keeping measures, there was no evidence that there were differences between the drivers in the experimental groups and those in the control group. There were no statistically significant interactions.

Average Velocity

As table 9 indicated, only one variable, the age of the driver, had a statistically significant effect on the average velocity at which the drivers drove during the two data-collection periods. The other independent variables—the data-collection period, the intra-string gap, and the method of transferring control—and the interactions between them were not significant.

<u>Age of the Driver.</u> Table 9 indicated that the average velocity was affected only by the age of the driver. The effect is shown in figure 5. The younger drivers drove faster than the older drivers: on average, they drove at 87.5 km/h (54.3 mi/h) and 84.2 km/h (52.4 mi/h), respectively.

Velocity Drift

The velocity drift is the rate at which the velocity of the vehicle increases or decreases as a function of the distance traveled along the lane. Mathematically, it is the gradient of the line of best fit of the actual velocities of the vehicle. As can be seen in table 9, the velocity drift was unaffected by the data-collection period, the age of the driver, the intra-string gap, or the method of transferring control. In addition, none of the interactions were significant.

Velocity Instability

The velocity instability is the variability in velocity that occurs when the driver is driving along the lane. Mathematically, it is the variability (i.e., the residual standard deviation) of the actual velocities of the vehicle about the line of best fit. Table 9 shows that the data-collection period had a statistically significant effect on the velocity instability. However, the remaining three

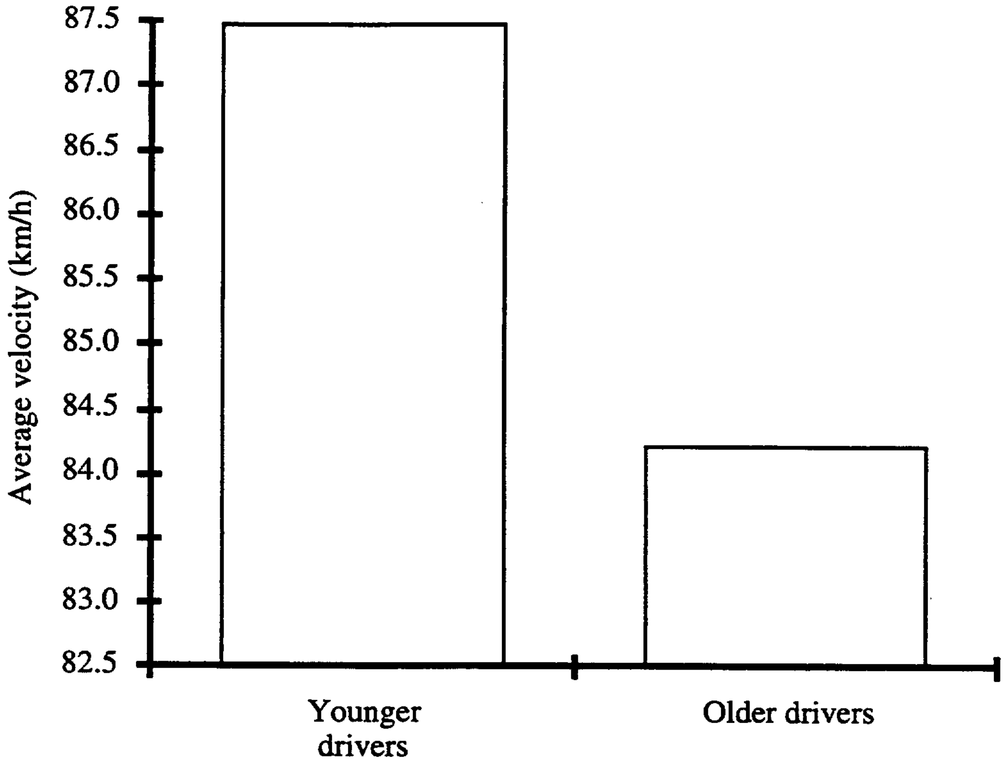

Figure 5. Mean velocity for older and younger drivers.

variables—the age of the driver, the intra-string gap, and the method of transferring control—did not affect the velocity instability. Also, none of the interactions were significant.

Data-collection period. The summaries of the intra-string gap ANOVA and the transfer-method ANOVA, which are shown in table 9, reveal that there were statistically significant differences in the steering instability means obtained in the early and late data-collection periods. The Tukey Studentized Range test was used to determine which steering instability means were significantly different; the results are shown in table 10.

The first line in table 10 shows that the mean velocity instability in the early data-collection period was significantly different from the steering instability in eight of the nine 1-min segments of the late data-collection period (the exception was the first 1-min segment of the late period). Similarly, the second line of table 10 indicates that the mean steering instability was significantly different in the first 1-min segment of the late period than it was in five of the remaining eight 1-min segments of that period. These significant differences are illustrated in figure 6.

Table 10. Results of all pairwise comparisons of average velocity instability between the early data-collection period and each 1-min segment of the late data-collection period.[a]

	Early Data-Collection Period	1-min Segment of the Late Data-collection period 1	2	3	4	5	6	7	8	9
Early Data-Collection Period		–	*	*	*	*	*	*	*	*
1			*	*	*	*	–	*	–	–
2				–	–	–	–	–	–	–
3					–	–	–	–	–	–
4						–	–	–	–	–
5							–	–	–	–
6								–	–	–
7									–	–
8										–
9										

[a] "-"means the comparison was not significant; "*" means the comparison was significant at $p \leq 0.05$. Thus, the "-" at the intersection of "early data-collection period" and "1" indicates that there was no significant difference between pre-AHS average velocity instability ("early data-collection period") and average velocity instability in the first minute post-AHS ("1").

Figure 6 shows that there was more velocity instability in the early data-collection period than there was in the late period. It also appears from the figure that there was more velocity instability in the first 1-min segment of the late period than there was in the rest of that period, but the difference was statistically significant in only five of the eight cases.

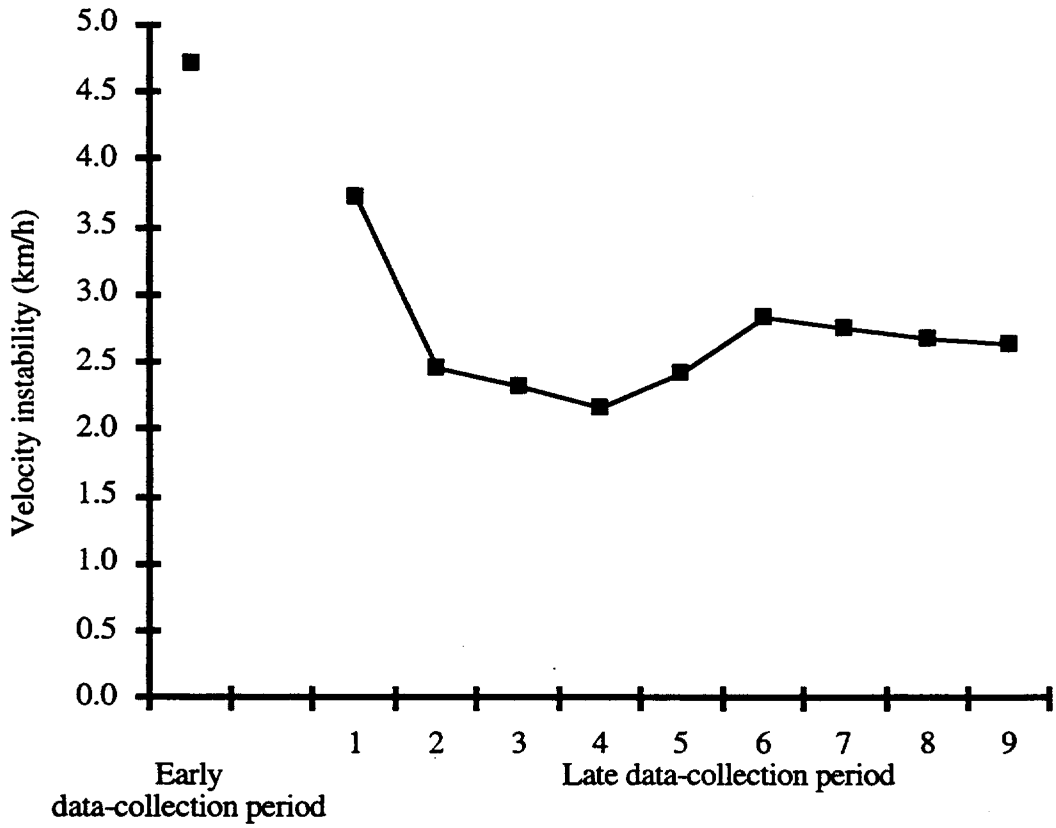

Figure 6. The mean velocity instability in the early data-collection period compared with the mean velocity instability in each of the nine 1-min segments in the late data-collection period.

Table 9 indicated that there was no statistically significant difference in velocity instability between the drivers in the control and experimental groups. Figure 7 shows that there was very little difference between the two groups of drivers. It also confirms the pattern, seen in figure 6, that there was a drop in velocity instability from the early data-collection period to the late period, and a drop from the first minute of the late period to the rest of that period.

The Number Of Velocity Fluctuations

The final speed-control measure is the number of velocity fluctuations (i.e., the number of times per minute that the plot of the actual velocities of the vehicle crosses the line of best fit). As shown in table 9, there was only one variable that had a statistically significant effect on the number of velocity fluctuations: as with the velocity instability, it was the data-collection period.

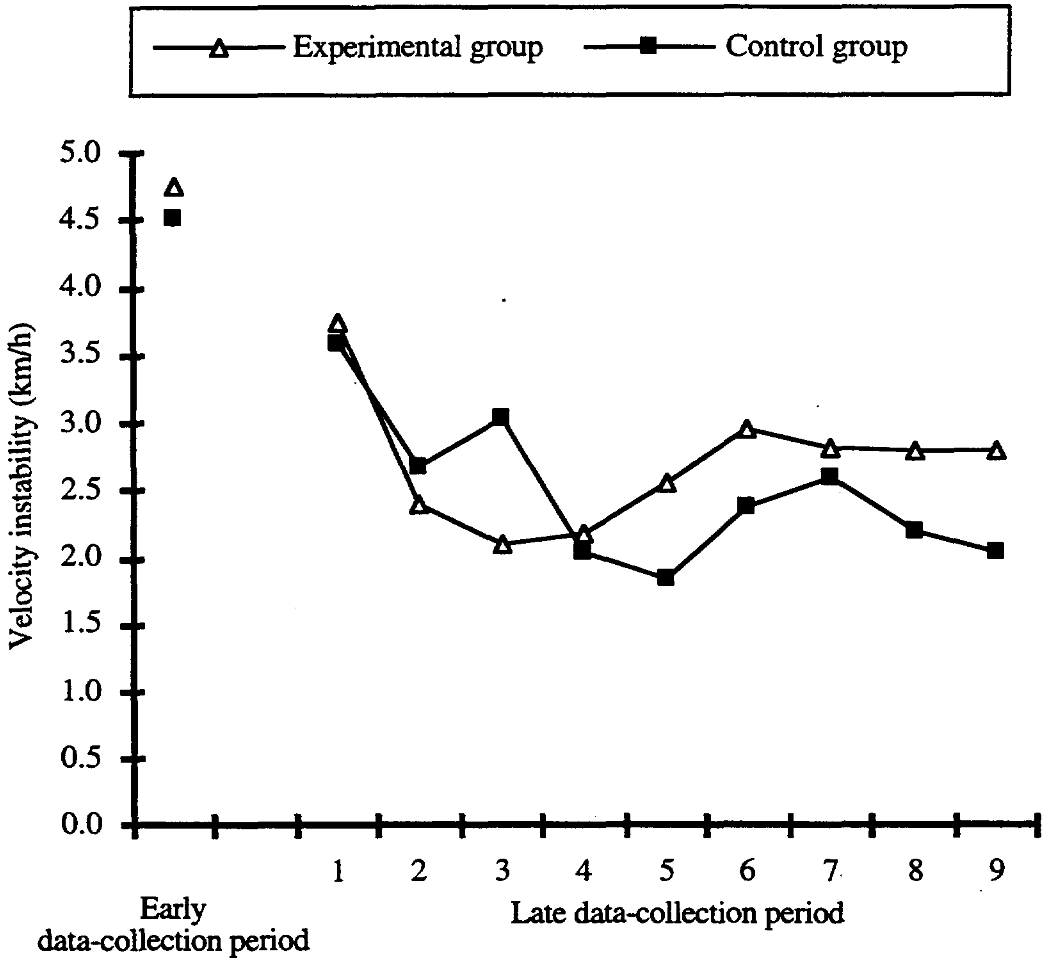

Figure 7. The mean velocity instability in the early data-collection period compared with the mean velocity instability in each of the nine 1-min segments in the late data-collection period for the drivers in both the control and experimental groups.

Data-collection period. The Tukey Studentized Range test was used to determine whether the mean number of velocity fluctuations in the early data-collection period was different from the number in any of the 1-min segments of the late data-collection period, and whether there were any differences in the number of velocity fluctuations among the 1-min segments. The results are shown in table 11.

Table 11. Results of all pairwise comparisons of average velocity fluctuations between the early data-collection period and each 1-min segment of the late data-collection period.[a]

		1-min Segment of the Late Data-collection period								
	Early Data-Collection Period	1	2	3	4	5	6	7	8	9
Early Data-Collection Period		–	–	*	*	*	*	*	*	*
1			–	–	–	–	–	–	–	–
2				–	–	–	–	–	–	–
3					–	–	–	–	–	–
4						–	–	–	–	–
5							–	–	–	–
6								–	–	–
7									–	–
8										–
9										

[a] "-"means the comparison was not significant; "*" means the comparison was significant at $p \leq 0.05$. Thus, the "-" at the intersection of "early data-collection period" and "1" indicates that there was no significant difference between pre-AHS average velocity fluctuations ("early data-collection period") and average velocity fluctuations in the first minute post-AHS ("1").

The first line in table 11 shows that the number of velocity fluctuations in the early data-collection period was significantly different from the number of fluctuations in seven of the nine 1-min segments of the late data-collection period (the exceptions occurred for the first and second 1-min segments). Figure 8 illustrates the effects. There were no statistically significant differences in the mean number of velocity fluctuations for any of the nine 1-min segments in the late data-collection period.

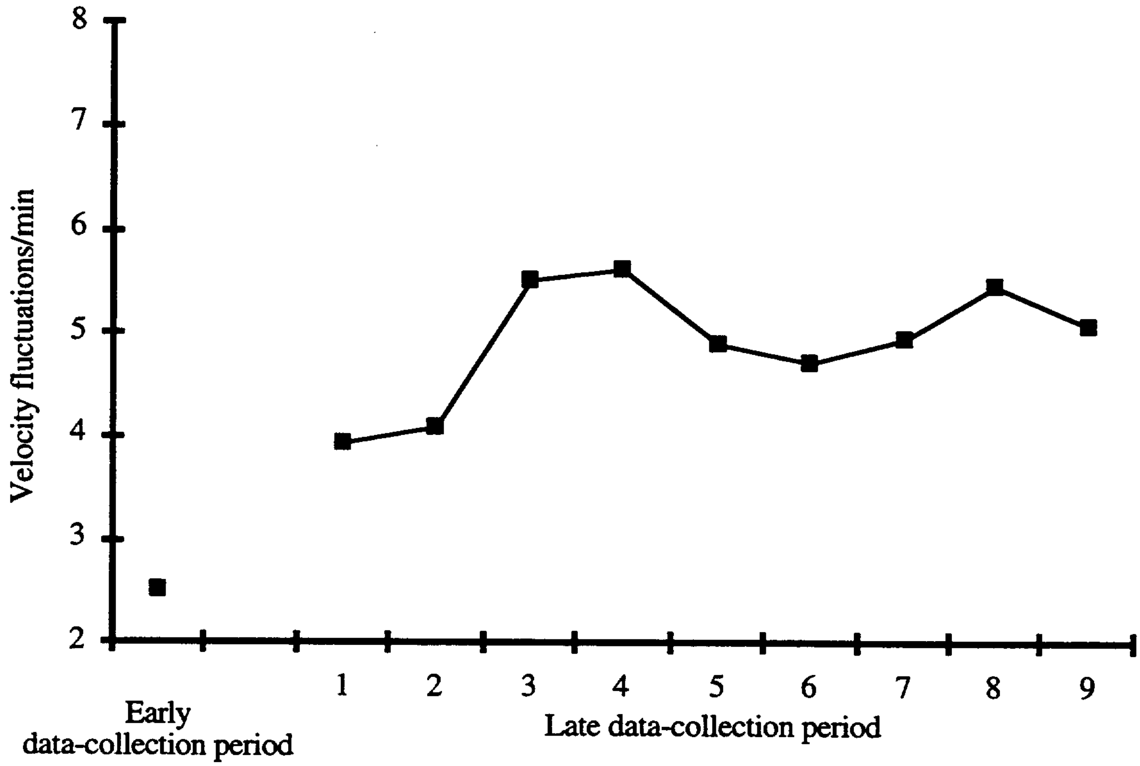

Figure 8. The mean number of velocity fluctuations in the early data-collection period compared with the mean number of velocity fluctuations in each of the nine 1-min segments in the late data-collection period.

Table 9 indicated that there was no statistically significant difference in velocity instability between the drivers in the control and experimental groups. The pattern seen in figure 8 (that of an increase in the number of velocity fluctuations from the early to the late data-collection period), as figure 9 shows, occurred for the drivers in both the control and experimental groups. It should be noted that, while figure 9 seems to indicate that there were more velocity fluctuations per minute for the drivers in the control group than there were for the drivers in the experimental group, the ANOVA revealed that this apparent difference was not statistically significant. However, when a two-tailed sign test was done on the data, it showed that the fact that the number of velocity fluctuations was greater for the control-group drivers than for the experimental-group drivers in nine of nine cases was significant ($p = 0.004$).

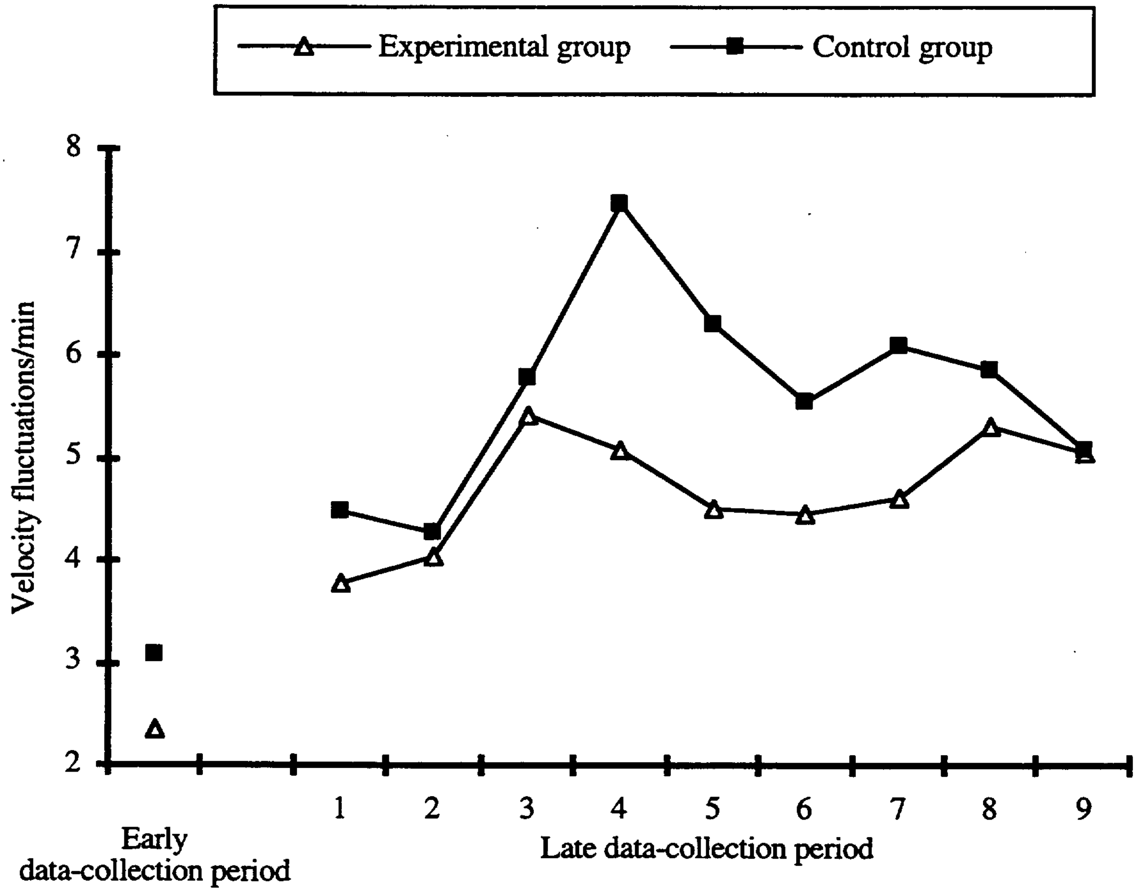

Figure 9. The mean number of velocity fluctuations in the early data-collection period compared with the mean number of velocity fluctuations in each of the nine 1-min segments in the late data-collection period for the drivers in both the control and experimental groups.

MINIMUM FOLLOWING DISTANCE

The minimum following distance data[1] were not segmented like the lane-keeping and speed-control measures. Instead, the minimum following distance for each driver was determined in

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[1] To determine the minimum following distance for each driver, the following procedure was used. First, throughout the two data-collection time periods, 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

both data-collection periods. The primary question relating to minimum following distance was whether traveling in the automated lane with a much-shorter-than-usual distance between the driver's car and the vehicle immediately ahead would cause the driver to reduce his/her following distance after experiencing travel in the AHS lane. As with the lane-keeping and speed-control measures, the minimum following distance data were analyzed using two ANOVA's, both of which investigated the effects of the data-collection period and the age of the driver. In addition, the first ANOVA investigated the effect of varying the intra-string gap (collapsing the data across the methods of transferring control), while the second ANOVA investigated the effect of varying the method of transferring control back to the driver (collapsing the data across the intra-string gaps). The statistically significant effects found by these two ANOVA's are listed in table 12. The complete summary tables for the both ANOVA's are presented in appendix 7.

Table 12. Summary of the statistically significant effects found in the ANOVA's conducted to determine if the minimum following distance was affected by the data-collection period (D), the age of the driver, the intra-string gap, or the method of transferring control.

	Minimum Following Distance	
Source	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]
D	0.0108	0.0083

[a] Control group is one level of intra-string gap.

[b] Control group is one level of transfer method.

Data-Collection Period. As table 12 shows, both ANOVA's found that the data-collection period had a statistically significant effect on the minimum following distance. The average minimum following distances found in these two periods are shown in figure 10.

Figure 10 shows that there was a reduction in the minimum following distance from the first data-collection period to the second. Since the means shown in the figure were averaged over all the drivers, including the controls, without further information it is not possible to determine whether this effect can be attributed to the driver's exposure to the AHS.

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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.

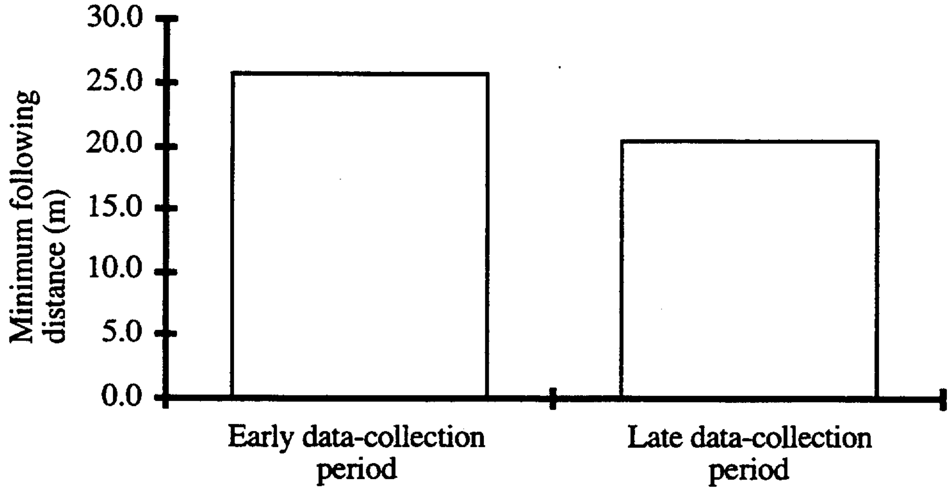

Figure 10. Minimum following distance in the first and second data-collection periods.

LANE-CHANGING BEHAVIOR

The percentage of time spent in the center and right lanes, the number of times the driver changed lanes, and the gaps that the driver moved into when changing lanes are discussed in this section.

Percentage of Time Spent in the Center and Right Lanes

During the early and late data-collection periods, the drivers could drive in the center and right lanes of the expressway: the left lane was reserved for automated vehicles. The total amount of time the drivers spent in the center lane and in the right lane was recorded. Then, these totals were converted into percentages. Since the percentage of time spent in the two lanes is inversely related, it was necessary to conduct ANOVA's on only one of the percentages. Accordingly, two ANOVA's were conducted on the percentage of time spent in the center lane. The first ANOVA determined the effect of varying the intra-string gap on the percentage of time the driver spent in the center lane after traveling under automated control. For this analysis, the data were collapsed over the methods of transferring control. The second ANOVA analyzed the effect of varying the method of transferring control, collapsing the data over the intra-string gaps. The independent variables and interactions that were found to have statistically significant effects are listed in table 13. The complete summary tables for these ANOVA's are presented in appendix 7.

Table 13. Summary of the statistically significant effects found in the ANOVA's conducted to determine if the percentage of time spent in the center lane (and right lane) was affected by the data-collection period (D), the age of the driver (A), the intra-string gap (I), or the method of transferring control (T).

	Percentage of Time in Center Lane	
Source	Intra-String Gap Analysis[a]	Transfer-Method Analysis[b]
I	0.0010	–
A	0.0028	0.0054
D	0.0189	0.0122
T	–	0.0161

[a] Control group is one level of intra-string gap.

[b] Control group is one level of transfer method.

Intra–String Gap. Table 13 indicates that the percentage of time spent in the center lane, and in the right lane, was affected by the intra-string gap. The Tukey Studentized Range test was used to investigate further. It showed that there was no difference in the percentage of time spent in the center (or right) lane by the drivers in the experimental groups, i.e., there were no differences that could be attributed to variations in the size of the intra-string gap. Instead, the difference that was significant was between the drivers in the control group and the drivers in the experimental groups, with the latter spending a greater percentage of time in the center lane than the former.

Data-collection periods. The summaries of the intra-string gap ANOVA and the transfer-method ANOVA, shown in table 13, reveal that there was a statistically significant difference in the percentage of time spent in the center lane (and in the right lane) in the early and late data-collection periods. Figure 11 illustrates this difference.

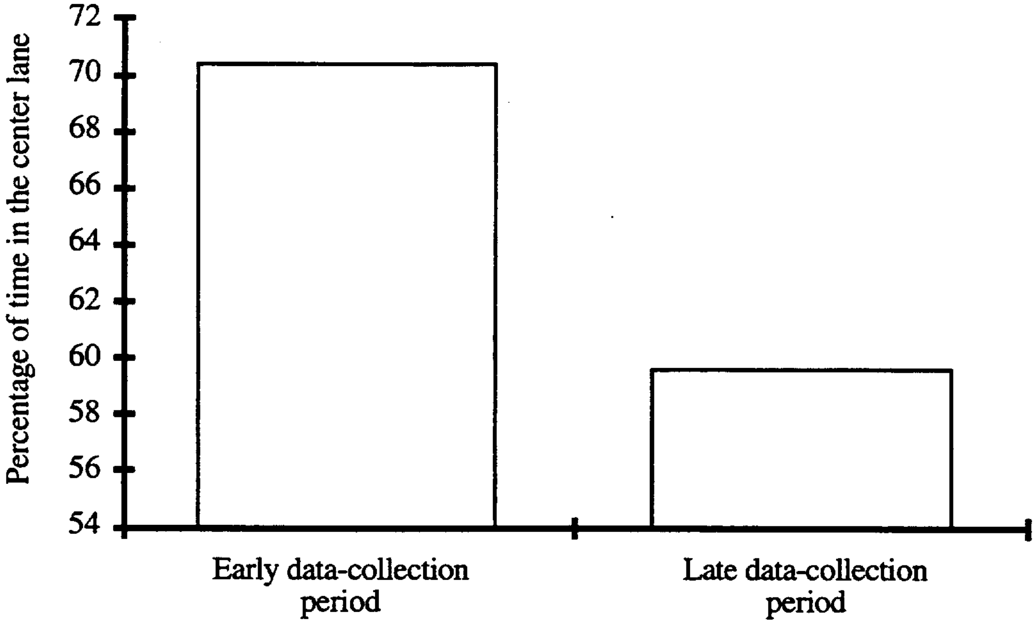

Figure 11. Percentage of time spent in the center lane in the early and late data-collection periods.

Figure 11 shows that, on average, drivers spent 11 percent more time in the center lane (and 11 percent less in the right lane) in the early data-collection period than they did in the late data-collection period. Since the percentages shown in the figure were averaged over all the drivers, including the control group, without further information it is not possible to determine whether this effect can be attributed to traveling in an automated lane.

Age of the Driver. Table 13 indicated that the percentage of time spent by the driver in the center lane (and in the right lane) varied with the age of the driver. Figure 12 shows this variation. The younger drivers drove in the center lane more often (and in the right lane less often) than the older drivers—81 percent and 50 percent of the time, respectively.

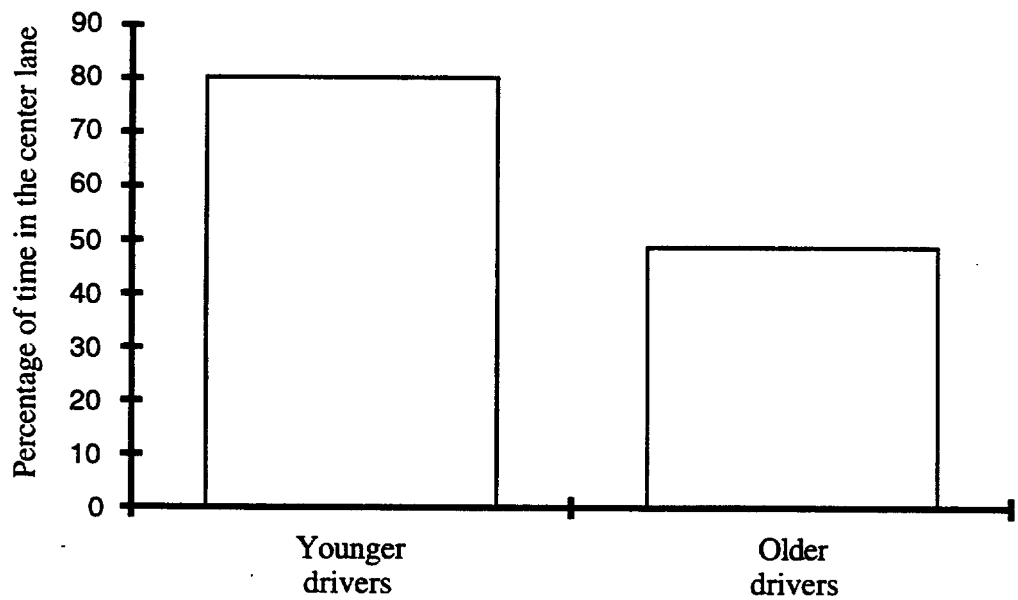

Figure 12. Percentage of time spent in the center lane by younger and older drivers.

Transfer Method. Table 13 indicated a significant effect of method of transferring control to the driver. The data are shown in figure 13. A Tukey Studentized Range test revealed that the difference was between the control group drivers and the experimental group drivers: the drivers in the control group spent less time in the center lane than did the experimental group drivers. Within the experimental group, method of transferring control did not matter.

Number of Lane Changes

As they were driving along the expressway during the two data-collection periods, the drivers were able move between the right and center lanes as they wished. Some drivers did not change lanes in one or both of the data-collection periods. A total of 167 lane changes were recorded in the two data-collection periods. The average numbers of lane changes per driver made in the early and late data-collection periods (before and after automated travel, respectively) are shown in table 14.

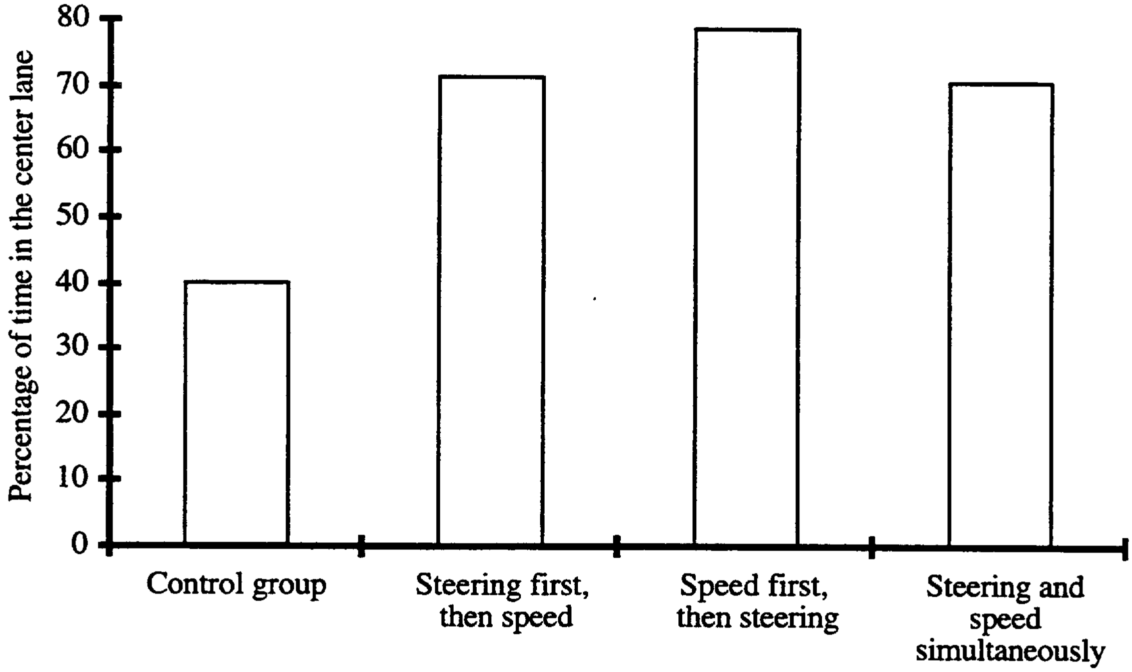

Figure 13. Percentage of time spent in the center lane as a function of control-transfer method.

Table 14. Average number of lane changes (rounded to one decimal place) for younger and older drivers in the control and experimental groups for both data-collection periods.

	Control Group		Experimental Group	
Data-Collection Period	Younger	Older	Younger	Older
Early	1.7	2.7	1.7	1.0
Late	1.2	2.2	2.3	1.8

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 15 and 16 show the rearranged data. For group by data-collection period (table 15), the chi-squared test on the data (using the correction for continuity) failed to reach significance ($\chi^2[1] = 3.18$, $p > 0.05$). Thus, group and data-collection period were independent of each other. For group by age (table 16), on the other hand, there was a significant interaction ($\chi^2[1] = 5.47$, $p < 0.02$). The average numbers of lane changes are shown in table 17.

Table 15. Total number of lane changes for each group by data-collection period combination.

Data-collection period	Control Group	Experimental Group
Early	26	48
Late	20	73

Table 16. Total number of lane changes for each group by age combination.

Age Group	Control Group	Experimental Group
Younger	17	71
Older	29	50

Table 17. Average number of lane changes (rounded to one decimal place) for each group by age combination.

Age Group	Control Group	Experimental Group
Younger	2.8	3.9
Older	4.8	2.8

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 in the early and late data-collection periods. The distance between the back bumper of the vehicle ahead and the front bumper of the vehicle behind in the adjacent lane was recorded. The paucity of data in the various cells of a potential ANOVA made it impossible to do the analysis. For all gaps ≤350 m (1148 ft)—an arbitrary cutoff point equivalent to a 14-s gap for vehicles traveling at the speed limit—the number of lane changes in each 25-m (82-ft) range was divided by the total number of lane changes to get the percentage within that range. Then, cumulative percentages were determined across the entire range of gaps that were plotted. The cumulative percentages of gap sizes accepted in lane

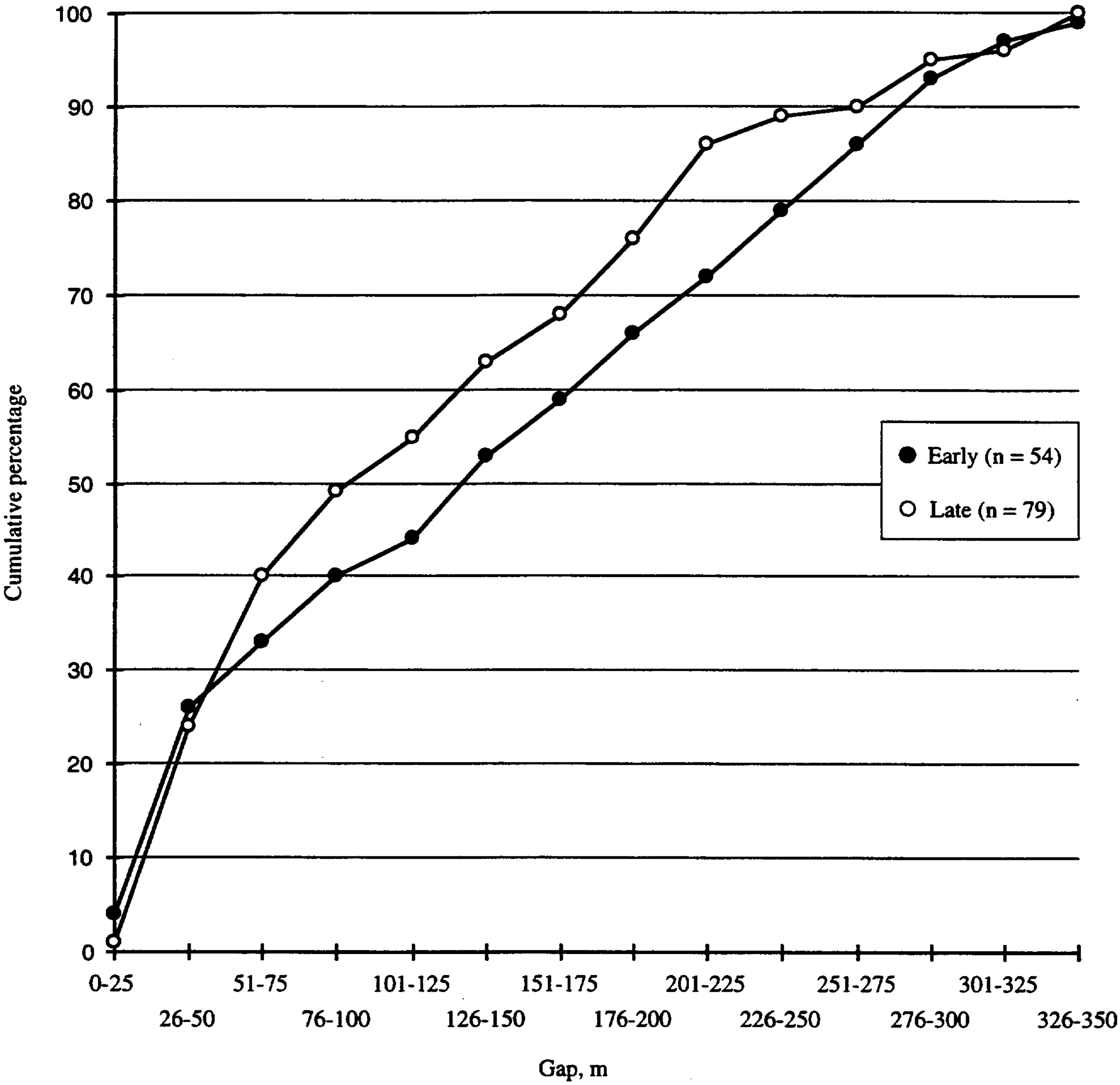

Figure 14. Cumulative percentage of gap size accepted in a lane change. [In the key, n is the number of lane changes plotted. Cumulative percentage may differ from 100 because of rounding error. (1 ft = 1 m x 3.28.)]

changes (subject to the constraint indicated above) are shown in figure 14 for the two data-collection periods, because (by inspection) there did not appear to be any difference between the experimental and control groups, their data were combined. The plots for the early and late data-collection periods are very similar. Based on the raw data (not shown in the report), there is a cluster of gaps between 40 m (131 ft) and 60 m (197 ft) in each data-collection period. Given that drivers drove at about the speed limit (88.6 km/h [55 mi/h]) in both periods, those gaps translate to about 1.6 s and 2.4 s, respectively.

INCURSIONS

Number of Incursions

During the two data-collection periods in this experiment (early and late; before and after automated travel, respectively), there were a number of lane incursions (i.e., occasions 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). There were 140 incursions during the two data-collection periods. Table 18 reports the average number of incursions per driver. 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 incursions were used instead. Tables 19 and 20 show the rearranged data. For group by data-collection period (table 19), the chi-squared test on the data (using the correction for continuity) failed to reach significance ($\chi^2[1] = 0.73, p > 0.35$). Thus, group and data-collection period were independent of each other. The test on group by age (table 20), on the other hand, was significant ($\chi^2[1] = 4.22, p < 0.04$), indicating that the number of incursions in each group was dependent on the driver's age. The average numbers of incursions are shown in table 21.

Table 18. Average number of incursions (rounded to one decimal place) for younger and older drivers in the control and experimental groups for both data-collection periods.

	Control Group		Experimental Group	
Data-Collection Period	Younger	Older	Younger	Older
Early	1.3	1.3	1.2	1.8
Late	1.3	0.5	1.0	2.3

Table 19. Total number of incursions for each group by data-collection period combination.

Data-Collection Period	Control Group	Experimental Group
Early	16	54
Late	11	59

Table 20. Total number of incursions for each group by age combination.

Age Group	Control Group	Experimental Group
Younger	16	40
Older	11	73

Table 21. Average number of incursions (rounded to one decimal place) for each group by age combination.

Age Group	Control Group	Experimental Group
Younger	2.7	2.2
Older	1.8	4.1

Size of Gap Rejected When Incursions Occurred

When each incursion occurred, the distance between the back bumper of the vehicle ahead and the front bumper of the vehicle behind in the adjacent lane was recorded. The limited data per cell made an ANOVA impossible. As with the gaps accepted in lane changes, for all incursion gaps that were less than 350 m (1148 ft), the number of incursions in each 25-m (82-ft) range was divided by the total number of incursions to get the percentage within that range. Then, cumulative percentages were determined across the entire range of gaps that were plotted. The cumulative percentages of gap sizes rejected in incursions (subject to the constraint indicated above) are shown in figure 15 for the two data-collection periods. Because (by inspection) there did not appear to be any difference between the experimental and control groups, their data were combined. The plots for the early and late data-collection periods are very similar. Based on the raw data (not shown in the report), there is a cluster of gaps between 40 m (131 ft) and 60 m (197 ft) in each data-collection period, just as there was for gap size accepted in a lane change. Given that drivers drove at about the speed limit (88.6 km/h [55 mi/h]) in both periods, those gaps translate to about 1.6 s and 2.4 s, respectively. It is also noted from the raw data that there were very few gaps shorter than 40 m (131 ft) that were rejected when incursions occurred, suggesting that drivers did not consider moving into gaps that were shorter than this.

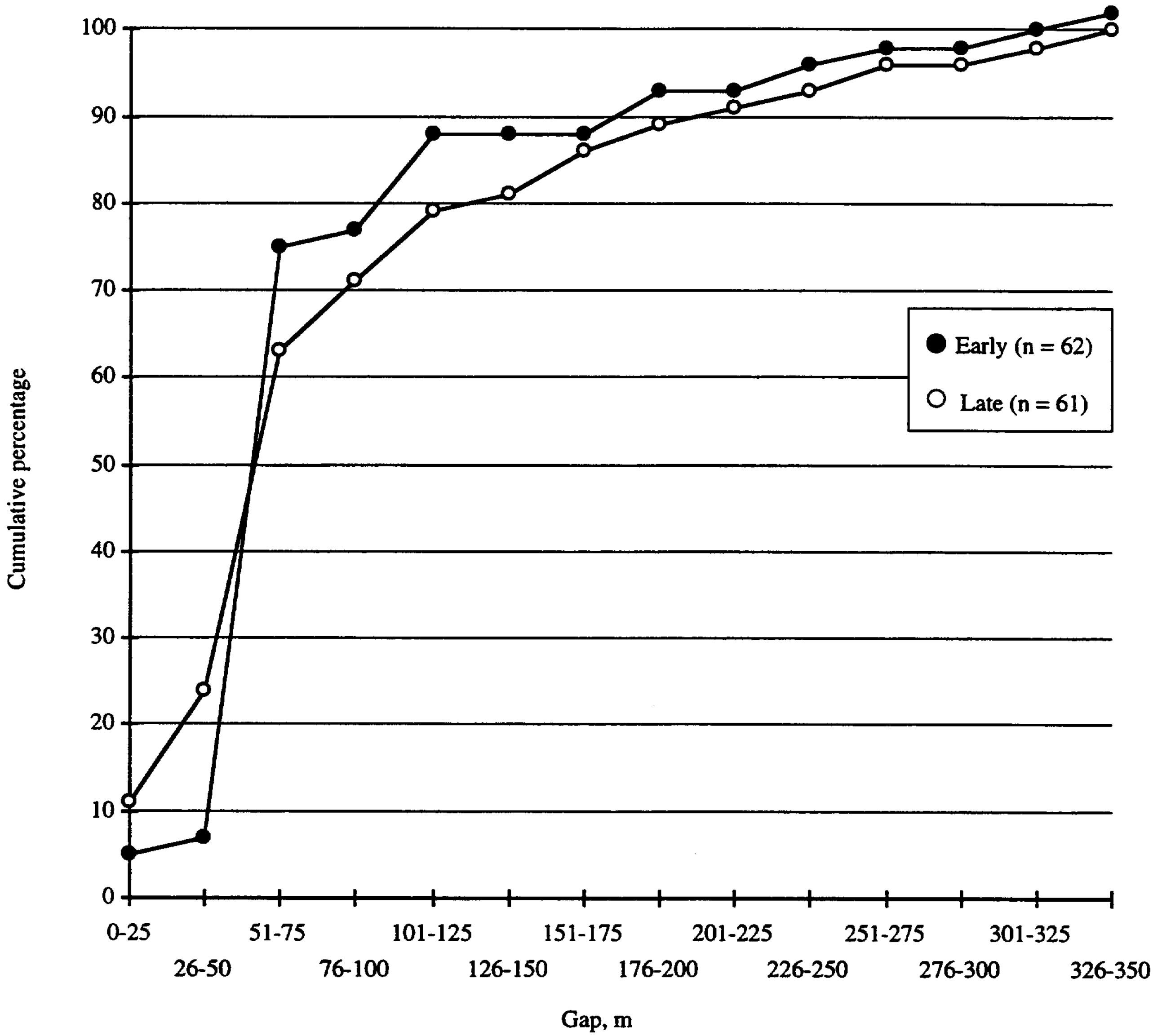

Figure 15. Cumulative percentage of gap size rejected in a lane incursion. [In the key, n is the number of lane changes plotted. Cumulative percentage may differ from 100 because of rounding error. (1 ft = 1 m x 3.28.)]

ACCEPTED VERSUS REJECTED GAPS

Since the shortest gaps accepted in lane changes and the shortest incursion gaps are very similar in length, it is reasonable to ask whether they are related (e.g., do drivers who have the shortest lane-change gaps also have the shortest incursion gaps?). To explore this relationship, the shortest gap into which each driver drove when changing lanes was compared with the shortest gap he/she rejected when there was an incursion. Pairs of values were found for each driver. For the purposes of this comparison, data from the early and late data-collection periods were combined. Then, the correlation between the pairs was tested using Spearman's correlation coefficient.[2] The value of ρ was found to be 0.22, and was not statistically significant. This means that the drivers who had the shortest incursion gaps were not the same drivers who had the shortest lane-change gaps.

QUESTIONNAIRE

Four versions of the questionnaire were used in this experiment: one for each of the three control-transfer methods and one for the control condition. Questions 1 through 6 and 28 through 30 were the same for all conditions. Question 7 was modified so that the drivers in the control group had a slightly different question than those exposed to the AHS. Questions 7 through 25 were administered only to the drivers who traveled in the AHS. Of these items, question 15 was modified to clearly state how the transfer of control from the AHS to driver was made in the particular experimental condition. A copy of each questionnaire is presented in appendix 4.

A scale ranging from 0 to 100 with negatively and positively worded anchors at the ends were 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. Dichotomous questions (numbers 9a, 10a, 11a, 12a, 16, and 29) asked the drivers to check a box indicating either yes or no. These items were scored as 0 for no and 1 for yes. Then, a series of ANOVA's was conducted on the data obtained to determine whether age, gender, transfer method, or intra-string gap had affected the responses of the drivers. The results of the analyses of the questions related to the current experiment are presented in the subsections that follow.

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[2] Spearman's ρ was used instead of the Pearson correlation coefficient because both the lane-change gap and the incursion gap data were positively skewed. Only gap data from drivers who changed lanes at least once and made an incursion at some point in either data-collection period could be used in calculating ρ. Some drivers did not change lanes and some did not have an incursion in either data-collection period.

Simulator Realism

The first six questions were presented to gather drivers' opinions on the realism of the Iowa Driving Simulator. No significant differences were found during the ANOVA's. The average response for each question appears in table 22. These means are collapsed across age, gender, transfer method, and intra-string gap.

Table 22. Simulator realism.

Question	Overall Mean
1. How much did you enjoy driving the simulator? 0. Not at all 100. A lot	79.2
2. How did driving in the simulator compare to driving in your car? 0. Very different 100. Very similar	54.9
3. How realistic was the view out of the windshield in the simulator? 0. Very artificial 100. Very realistic	64.5
4. How realistic were the sounds in the simulator? 0. Very artificial 100. Very realistic	66.8
5. How realistic was the vehicle motion in the simulator? 0. Very artificial 100. Very realistic	73.1
6. While driving the simulator, how did you feel? 0. Did not feel well 100. Felt fine	81.0

As can be seen from table 22, all responses averaged above 50, indicating that the drivers had positive attitudes toward the simulator. The responses to three questions were strongly positive, with means above 70—implying that drivers enjoyed driving the simulator (question 1), found the vehicle motion to be realistic (question 5), and felt well while driving the simulator (question 6). Responses to questions 3 and 4 were moderately favorable with means between 60 and 70. These averages indicate that the view out of the windshield and sounds from the simulator were moderately realistic. The average response to the second question was neutral, with a mean of 54.9, indicating that drivers did not feel that driving the simulator was very different from or very similar to driving their own cars.

Designated AHS Velocity and Intra-String Gap

The responses for questions 7 and 8, which dealt with the designated AHS velocity and the intra-string gap, appear in tables 23 and 24.

Table 23. Designated AHS velocity and intra-string gap (question 7).

Question (Control group only)	Overall Mean		
7. In this study, how did you feel about the fact that while you were driving, one of the lanes (the left) was not available for you to use? 0. It didn't matter 100. It mattered a lot	48.5		
Question (Experimental groups only)	Both Steering & Velocity	Steering First then Velocity	Velocity First then Steering
7. In this study, when your car was under automatic control, how did you feel about the speed at which you traveled? 0. Would have preferred to go much slower 100. Would have preferred to go much faster	80.5*	71.3	59.6*

* Indicates these means are significantly different from each other.

Table 24. Designated AHS velocity and intra-string gap (question 8).

Question		
8. In this study, when your car was under automatic control, how did you feel about the separation distance between you and the car ahead? 0. Would have preferred a much longer separation 100. Would have preferred a much shorter separation	Younger	Older
Small Gap	28.9	41.7
Large Gap	42.2	23.8

Question 7 dealt with the use of the automated lane. This question was modified for the control group to focus on how the driver felt about not having access to the left (automated) lane. The question posed to the experimental groups dealt with the drivers' perceptions of the designated AHS velocity. The ANOVA's carried out on these questions showed statistically significant differences for the experimental groups only. As can be seen from table 23, the mean response of the control group indicated that these drivers were neutral about the lack of access to the left (automated) lane. For those traveling in the AHS, a preference for faster velocities in the automated lane was expressed by all groups. The statistically significant difference found for the experimental group indicated that those with the Both Steering and Velocity transfer method would have preferred a much faster speed than those with the Velocity First transfer method. No statistically significant difference was found between the Steering First transfer method and the other two transfer methods.

Question 8 dealt with separation distances in the automated lane. The ANOVA conducted on the responses to this question indicated that there was a statistically significant interaction between the age of the driver and the intra-string gap. Table 24 shows that the younger drivers who experienced the small intra-string gap and the older drivers who experienced the large intra-string gap preferred a longer separation distance than the older drivers with the small intra-string gap and the younger drivers with the large intra-string gap. It is important to note that the means of all groups indicate that a longer separation distance was preferred by all.

Information Display

Questions 9 through 12 dealt with information displays used as part of this experiment. Statistical analyses using ANOVA were conducted on each question. Statistical differences were found for only questions 10b and 12b. Results for all other questions are collapsed across age, gender, transfer method, and intra-string gap. The results are shown in tables 25 and 26.

As can be seen from table 25, the mean responses for the questions where no significant differences were found indicate that the drivers in the experimental groups used the Current Location (question 9a), Next Exit (question 10a), Time to Destination (question 11a), and Traffic Ahead information (question 12a). Mean responses on the usefulness of the Current Location (question 9b) and Time to Destination (question 11b) information indicated that drivers found this information to be useful. While drivers also found the Next Exit information to be useful, there were statistically different responses from the older and younger drivers (question 10b): Older drivers found the Next Exit information to be significantly more useful than did the younger drivers.

Table 25. Information display (questions 9a through 12a).

Question	Overall Mean	
9a. Did you look at the CURRENT LOCATION information during the experiment? 0. No 1. Yes	1.0	
9b. How useful did you find the CURRENT LOCATION information? 0. Not useful 100. Very useful	72.5	
10a. Did you look at the NEXT EXIT information during the experiment? 0. No 1. Yes	1.0	
Question	**Younger**	**Older**
10b. How useful did you find the NEXT EXIT information? 0. Not useful 100. Very useful	62.2	85.0
Question	**Overall Mean**	
11a. Did you look at the TIME TO DESTINATION information during the experiment? 0. No 1. Yes	1.0	
11b. How useful did you find the TIME TO DESTINATION information? 0. Not useful 100. Very useful	82.6	
12a. Did you look at the TRAFFIC AHEAD information during the experiment? 0. No 1. Yes	1.0	

Table 26. Information display (question 12b).

Question		
12b. How useful did you find the TRAFFIC AHEAD information? 0. Not useful 100. Very useful	Younger	Older
Small Gap	78.8	90.8
Large Gap	91.7	58.8

A statistically significant interaction between the age of the driver and the intra-string gap distance was found for question 12b. Older drivers with the small intra-string gap and younger drivers with a large intra-string distance found the traffic ahead information to be more useful than older drivers with a large intra-string gap and younger drivers with a small intra-string gap.

AHS Message

Question 14 dealt with the clarity of the AHS messages presented during this experiment. The ANOVA carried out on this question failed to show any statistical difference in responses. The average response reported in Table 27 is collapsed across age, gender, transfer method, and intra-string gap. Responses to this question indicate that the AHS messages were very easy to understand.

Table 27. AHS message.

Question	Overall Mean
14. How understandable were the messages saying that you should take control of the car? 0. Very hard to understand 100. Very easy to understand	99.7

Transfer of Control from the AHS to the Driver

Questions 15 through 18 dealt with transfer of control from the AHS to the driver. The ANOVA's conducted on these data showed that there were statistically significant differences in the responses for questions 15 and 16 by drivers who experienced the different transfer methods. The results for these two questions are presented in table 28.

The responses to question 15 indicate that drivers who gained control of both the steering and velocity simultaneously rated this transfer method significantly better than those who gained control of velocity first and then steering. There were no statistically significant differences between the ratings of drivers with the steering-first (then velocity) transfer method and drivers in the other two transfer methods. When asked in question 16 if they would have preferred to be given control in some other way, drivers in the velocity-first (then steering) transfer group preferred a different method significantly more than drivers in either the both steering and velocity and the steering-first (then velocity) transfer methods.

Table 28. Transfer of control from AHS to driver (questions 15 and 16).

Question	Both Steering & Velocity	Steering First then Velocity	Velocity First then Steering
15. When you were given back control of the car after the period of automated travel, you took control of (both steering and speed at the same time)/(steering first followed by speed)/(speed first followed by steering). How did you feel about getting control back in this way? 0. This way was very bad 100. This way was very good	97.1*	86.3	77.1*
16. Would you have preferred to have been given control of the car back in some other way? 0. No 1. Yes	0.00^A	0.00^A	0.33^B

* Indicates these means are significantly different from each other.
"A" means are significantly different from "B" means, but not from each other.

The ANOVA for questions 17 and 18 failed to show statistically significant differences. Table 29 shows means for these questions. The means are collapsed across age, gender, transfer method, and intra-string gap. These results indicate that the drivers felt their driving was very controlled immediately after leaving the automated lane (question 17) and that driving at the end was relatively the same as driving at the beginning of the session (question 18).

Table 29. Transfer of control from AHS to driver (questions 17 and 18).

Question	Overall Mean
17. How would you describe the manner in which you controlled your car *immediately after leaving* the automated lane? 0. Very uncontrolled 100. Very controlled	76.9
18. *After leaving the automated lane*, you drove for about 10 minutes. How was your driving at the end of the 10 minutes compared to the beginning? 0. Driving at the end was very different from driving at the beginning 100. Driving at the end was the same as driving at the beginning	66.1

Attitude Toward AHS

Questions 19 through 25 dealt with drivers' attitudes toward the AHS. A statistical analysis was performed on each question. A statistically significant difference was found between younger and older drivers for question 19, indicating that older drivers preferred the automated lanes more than younger drivers. No statistically significant differences were found for questions 20 through 24. Results for these questions are collapsed across age, gender, transfer method, and intra-string gap. Table 30 presents the results for questions 19 through 24. Table 31 gives the responses for question 25.

Table 30. Attitude toward AHS (questions 19 through 24).

Question	Younger	Older
19. Which lane did you prefer to be in? 0. Strongly preferred manual lane 100. Strongly preferred automated lane	63.3	83.9
Question	**Overall Mean**	
20. Which lane was it more challenging to be in? 0. More challenging in the manual lanes 100. More challenging in the automated lane	10.4	
21. How would you feel if an Automated Highway System were installed on I-380 between Iowa City and Waterloo? 0. Very unenthusiastic 100. Very enthusiastic	69.8	
22. If an Automated Highway System were installed on I-380, which lane would you prefer driving in? 0. Would strongly prefer manual lanes 100. Would strongly prefer automated lanes	71.7	
23. If an Automated Highway System were installed on I-380, how would you feel about your safety? 0. Would feel much safer without an Automated Highway System 100. Would feel much safer with an Automated Highway System	66.7	
24. How would the installation of an Automated Highway System affect the stress of driving? 0. Would greatly decrease stress 100. Would greatly increase stress	26.0	

Table 30 indicates that drivers found the manual lanes to be more challenging (question 20), would be enthusiastic about an AHS being installed on a nearby interstate (question 21), would prefer to drive in the automated lanes if this installation were to take place (question 22), would

Table 31. Attitude toward AHS (question 25).

Question	Both Steering & Velocity	Steering First then Velocity	Velocity First then Steering
25. How much would you like to be told as to why the Automated Highway System is doing things with your vehicle such as accelerating, lane changing, and so on? 0. Not at all 100. A lot	72.1	57.1*	89.1*

* Indicates these means are significantly different from each other.

feel safer in an AHS (question 23), and would experience a decrease in stress if an AHS existed (question 24).

Table 31 indicates that the drivers in the velocity-first transfer group would have preferred significantly more information about the things that the vehicle was doing, such as accelerating, lane changing, and so on, than those in the steering-first transfer method group. The drivers in the group where control of the steering and velocity were regained simultaneously did not differ significantly from the other transfer-method groups in their response.

Cruise Control

Questions 29 and 30 dealt with cruise control. Results for these questions are presented in tables 32 and 33. Only the 32 drivers who answered "yes" to question 29 answered question 30.

Table 32. Cruise control (question 29).

Question	Younger	Older
29. Does your vehicle have cruise control? 0. No 1. Yes	0.50	0.92

Small Gap	Large Gap	Controls
0.83	0.78	0.42

Table 33. Cruise control (question 30).

Question	Overall Mean
30. How often do you use the cruise control on your vehicle? 0. Hardly ever 100. Almost always	78.4

The ANOVA conducted on these data indicated that significantly more of the older drivers had cruise control in their vehicles than did the younger drivers. Additionally, significantly more individuals in both the large and small intra-string gap conditions had cruise control in their vehicles than those in the control condition. No interaction effects were found between age and intra-string gap size. Question 30 asked drivers with cruise control how often they use this feature: No significant differences were found. The average for question 30 indicates that those drivers with cruise control use it very frequently.