WHEN NO DIFFERENCE MAKES A DIFFERENCE: OLDER DRIVERS, MEDICAL CONDITIONS, AND FREEWAY RAMP NEGOTIATION

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ABSTRACT

Exploratory analyses of vehicle kinematic data contained in the SHRP2 Naturalistic Driving Study database contrasted the performance of older drivers with and without medical conditions including COPD, neuropathy, and Parkinson's disease, during the negotiation of freeway ramps and acceleration lanes in the Tampa/St. Petersburg, FL, area. Two sets of ramps identified in the SHRP2 Roadway Information Database were defined as exhibiting 'more favorable' versus 'less favorable' geometric design characteristics, with correspondingly lower versus higher levels of driving task demand for ramp negotiation. It was hypothesized that reducing the demand for negotiating ramps would have a greater benefit for the drivers with medical conditions than for drivers without medical conditions, as reflected in measures of speed, acceleration, and brake applications. Results demonstrated significant main effects of ramp design on driver performance but the only effect of driver group was that the older drivers with medical conditions allowed a longer gap between themselves and a lead vehicle than drivers without medical conditions. No interactions between driver group and ramp design were found. One possible explanation for these findings is an absence of significant differences between driver groups on key indices of functional status. A discussion emphasizes the positive implications for older drivers maintaining their mobility. This includes older drivers with serious medical conditions, assuming such conditions are controlled.

Keywords: Older driver, medical condition, driving performance, ramp, acceleration lane

INTRODUCTION

Among the many voices that articulate a blueprint for healthy aging, few would dispute that maintaining independent personal mobility in one's community is vital, and that the preferred mobility option for a vast majority of older people is the private automobile. At the same time, medical conditions that are more prevalent among older individuals lead to impairments in visual, cognitive, or psychomotor functions needed to drive safely (American Medical Association, 2010).

'Environmental support' in the form of age-friendly highway design features has been promoted as one way to accommodate our aging population. However, such design recommendations exist as guidelines, not standards or warrants (cf. Brewer, Murillo, and Pate, 2014) and accordingly will be implemented incrementally; retrofitting the entire highway system is simply not practical. Therefore we can expect considerable variability in "goodness of design" – vis-a-vis accommodating older driver needs – in the highway system for many years to come.

This raises a research question with potentially significant implications for senior mobility and independence: Are there operationally-significant performance differences between older drivers with serious medical conditions and age-matched healthy controls, when negotiating a demanding driving situation characterized by a more favorable versus less favorable design? An exploratory study mining a preexisting data set was carried out to address this question, with somewhat unexpected but not altogether unwelcome findings.

METHOD

Samples of drivers aged 65 and older with specified medical conditions, and similarly-aged drivers without any self-reported medical conditions were identified in the Naturalistic Driving Study (NDS) database generated as a product of the second Strategic Highway Research Program (SHRP2). The SHRP2 effort collected roadway, driver, and environment data for over three thousand drivers at sites in six different states, who drove a total of six-and-a-half million trips in which their own cars were instrumented with cameras, radar, and other sensors. Detailed information on the SHRP2 NDS in-vehicle data acquisition systems (DAS) and data collection methodology can be found in the Field Data Collection Report S2-S07-RW-1 and other published reports available at the Transportation Research Board's SHRP2 publication site (http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/PublicationsSHRP2.aspx).

The data analyzed in this research were collected at only one of the SHRP2 sites – Tampa/St. Petersburg, FL – for a subset of trips completed by the two driver groups noted above, i.e., trips that included the traversal of selected ramps and acceleration lanes used when merging onto a freeway. The data were obtained from the Virginia Tech Transportation Institute (VTTI), the sole custodian of NDS data at the time these analyses were carried out.

The sample of drivers in a combined medical conditions (MC) group self-reported a medical diagnosis of Parkinson's disease (n = 1), peripheral neuropathy (n = 6), or chronic obstructive pulmonary disease (COPD) (n = 6); thus for the MC group, in total, n = 13. These conditions were targeted based on recommendations of an expert panel of physicians and Driving Rehabilitation Specialists who considered the severity of the crash risk associated with hazardous driving errors linked to each condition; the availability and effectiveness of countermeasures to mitigate each condition; and the anticipated prevalence of each of the candidate medical conditions among the aging driver population in the foreseeable future. Panelists were convened under a task in the U.S.DOT/NHTSA project, "*The Effects of Medical Conditions on Driving Performance.*" In addition, a control (C) group (n = 23) with no reported medical conditions was identified in the NDS database.

The distribution of driver ages for the C and MC groups using 5-year age cohorts is presented in Table 1; the exact date of birth of SHRP2 participants, considered to be Personally Identifiable Information (PII), was not available to the research team. The percent of the C and MC groups that were male was 57% and 61%, respectively.

TABLE 1 Distribution of driver ages by 5-year cohorts, for each study group.

Group	n	Age Group 65-69		Age Group 70-74		Age Group 75-79		Age Group 80-84	
		n	%	n	%	n	%	n	%
Control	**23**	**5**	**21.7%**	**6**	**26.1%**	**10**	**43.5%**	**2**	**8.7%**
Medical Condition	**13**	**5**	**38.5%**	**4**	**30.8%**	**3**	**13.0%**	**1**	**7.7%**
COPD	6	1	16.7%	3	50.0%	2	8.7%	0	0.0%
Neuropathy	6	4	66.7%	1	16.7%	0	0.0%	1	16.7%
Parkinson's	1	0	0.0%	0	0.0%	1	4.3%	0	0.0%
Total	**36**	**10**	**27.8%**	**10**	**27.8%**	**13**	**36.1%**	**3**	**8.3%**

The functional status of the C and MC groups is described by scores on a battery of visual, physical, and cognitive measures. As displayed in Table 2, the average far bilateral visual acuity of the two study groups was nearly identical. Figure 1 shows that the contrast sensitivity (best eye) for the C and MC groups also match up well, and both are within the normal range using population norms established by test developers at each spatial frequency tested. An Optec 6500 Vision test machine was used for these measures.

TABLE 2 Far bilateral visual acuity scores, by study group.

Group	n	Minimum (20/__)	Maximum (20/__)	Average (20/__)	Standard Deviation (20/__)
Control	**23**	**12.5**	**50**	**24.39**	**8.36**
Medical Condition	**13**	**16**	**50**	**24.77**	**9.31**
COPD	6	16	32	22.17	5.60
Neuropathy	6	16	32	23.17	6.18
Parkinson's	1	50	50	50.00	0.00
Total	**36**	**12.5**	**50**	**24.53**	**8.59**

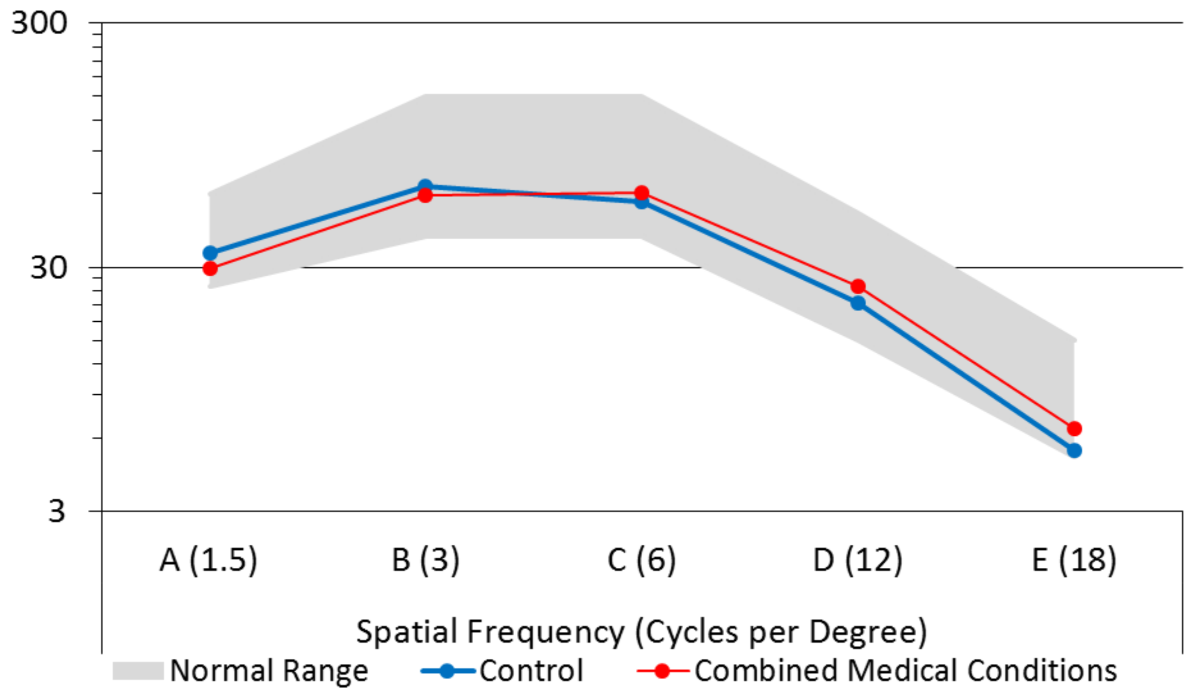

FIGURE 1 Contrast sensitivity scores (best eye), by study group.

The physical ability of each group as characterized in terms of their performance on the rapid pace walk. Rapid-pace walk times were available for 35 of the 36 drivers in this sample, with the MC group described by a slightly longer (poorer) average time (6.25 s) than the control group (5.60 s). Rapid pace walk times are reported in Table 3.

TABLE 3 Rapid pace walk scores, by study group.

Group	N	Minimum Score (sec.)	Maximum Score (sec.)	Average Score (sec.)	Standard Deviation (sec.)
Control	**23**	**3.21**	**8.35**	**5.60**	**1.28**
Medical Condition	**12**	**4.51**	**9.47**	**6.25**	**1.40**
COPD	6	4.51	7.99	6.24	1.20
Neuropathy	5	5.04	9.47	6.54	1.75
Parkinson's	1	4.88	4.88	4.88	0.00
Total	**35**	**3.21**	**9.47**	**5.82**	**1.34**

The study groups are described by three measures of cognitive status: the Useful Field of View, subtest 2; the Trail-making Test, Part B; and Visualizing Missing Information (a derivative of the Motor-free Visual Perception Test, Visual Closure subtest). As shown in Tables 4, 5, and 6, the MC group was described by slightly *better* scores than the controls on UFOV® and Trails B, while the C and MC groups were equivalent, on average, with respect to their VMI scores.

TABLE 4 Useful Field of View subtest 2 scores, by study group.

Group	N	Minimum Score (msec.)	Maximum Score (msec.)	Average Score (msec.)	Standard Deviation (msec.)
Control	**23**	**100**	**327**	**161.48**	**88.02**
Medical Condition	**13**	**100**	**360**	**155.69**	**74.99**
COPD	6	100	170	111.67	28.58
Neuropathy	6	100	360	195.67	91.20
Parkinson's	1	180	180	180.00	0.00
Total	**36**	**100**	**360**	**159.39**	**82.50**

TABLE 5 Trail-making Test Part B scores, by study group.

Group	N	Minimum Score (sec.)	Maximum Score (sec.)	Average Score (sec.)	Standard Deviation (sec.)
Control	**23**	**36.9**	**147.3**	**100.5**	**29.4**
Medical Condition	**13**	**65.6**	**128.9**	**94.1**	**22.0**
COPD	6	65.6	128.9	88.2	23.9
Neuropathy	6	71.1	121.4	95.6	20.1
Parkinson's	1	120.6	120.6	120.6	0.0
Total	**36**	**36.9**	**147.3**	**98.2**	**26.8**

TABLE 6 Visualizing Missing Information scores, by study group.

Group	N	Minimum (Errors)	Maximum (Errors)	Average (Errors)	Standard Deviation
Control	**23**	**0**	**8**	**2.74**	**2.56**
Medical Condition	**13**	**0**	**7**	**2.77**	**2.39**
COPD	6	1	6	2.33	1.97
Neuropathy	6	0	7	2.67	2.73
Parkinson's	1	6	6	6.00	0.00
Total	**36**	**0**	**8**	**2.75**	**2.47**

The performance of the C and MC group drivers was contrasted for a number of dependent measures available in the NDS database that were viewed as indicators of the ability to smoothly and confidently negotiate freeway ramps. These included maximum speed; mean speed; maximum longitudinal acceleration and deceleration; number of brake applications; and cumulative time where headway (gap to vehicle ahead) was >3.5 and less than 3.5 seconds.

The selection of specific freeway ramps for which to compare the performance of the C and MC groups began by identifying all single lane entrance ramps and terminals of controlled access roads of functional class 1 and 2 in the Tampa/St. Petersburg area, that involve an entrance maneuver. Functional class 1 roads allow for high volume, maximum speed traffic movement between and through major metropolitan areas. Access to the road is usually controlled. Functional class 2 roads include roads used to channel traffic to functional class 1 roads for travel between and through cities in the shortest amount of time.

The single-lane free flow terminals/entrances were evaluated in respect to their compliance to AASHTO guidelines (AASHTO, 2011; Darren et al., 2012). Specifically, the minimum length of acceleration lane given by the Green Book was compared to the available acceleration length. For each ramp, the minimum length given by the Green Book was compared to the sum of the length of the speed change lane (SCL), that is the distance from the painted nose at the gore of the entrance ramp to the beginning of the taper (when the lane becomes narrower than 3.6m), and the distance from the controlling curvature to the painted nose, to determine if it met the 2011 Green Book design criterion for the minimum acceleration length.

It is important to note that no ramps were deficient with respect to AASHTO (AASHTO 2011) design criteria. However, based on the judgment of a road safety engineer on our research team, 24 ramps were identified that could be sorted into two groups: those with design elements that were relatively more favorable to drivers (n = 13) versus those that were relatively less favorable to drivers (n = 11).

A 'less favorable' designation was associated with the following problems: Seven ramps have controlling curves on the ramp proper with radius ≤80m, i.e. in the lower-range of ramp design speed. However, with respect to general ramp design considerations for loops and highway design speeds above 80km/h (50mph) and below 120 km/h (75mph), the loop lower – range values of design speed fall between 50km/h and 60km/h, which, in turn, correspond to a minimum radius of 80m to 125m respectively (see Table 10-1 in AASHTO 2011). Such small curve radii may result in a larger steering wheel angle, which potentially increases steering error. Drivers may compensate by choosing a lower speed, probably resulting in difficulty in accelerating up to the highway speed during merging (Winsum and Godthel, 1996).

Three ramps are associated with short gap acceptance length (≤90m (300ft)) (see Figure 10-69 in AASHTO 2011). Two of these ramps are associated with additional problems: in one case, moreover, there is a split on the approach of the ramp where drivers are required to make two maneuvers (make a decision regarding their direction and subsequently an entrance maneuver) in relatively quick succession (considering the speed on tangent section); in the other case, drivers who enter the freeway might have an obstructed view of the traffic on the freeway approaching the gore due to a left curved freeway alignment before the entrance ramp.

Finally, there is one ramp with a part of the speed change lane on a right curve; drivers on the ramp during the entrance may have difficulties in merging since they are required to align their car with highway to afford mirror view of overtaking traffic and monitor gap while steering as necessary to maintain position in the speed change lane.

Using the SHRP2 Roadway Information Database (RID), we provided VTTI with Link IDs for each location/ramp of interest, including a reference GPS coordinate (node) corresponding to the tip of the painted gore at each junction. VTTI then extracted vehicle kinematic data from the NDS for each traversal of each ramp by each driver in our sample, sorted into intervals 15 seconds before and 15 seconds after a driver traversed the reference coordinate. This data sort was performed because the driving task demands on the ramp before reaching the gore are distinct from those after the driver reaches the acceleration lane and is preparing to merge with traffic on the mainline. Additionally, the variability in ramp geometry was much greater before the gore; after that node, the acceleration lane geometry was more homogeneous across sites. In the Figure 2 examples, a red dot marks the location of the reference node at the ramp gore.

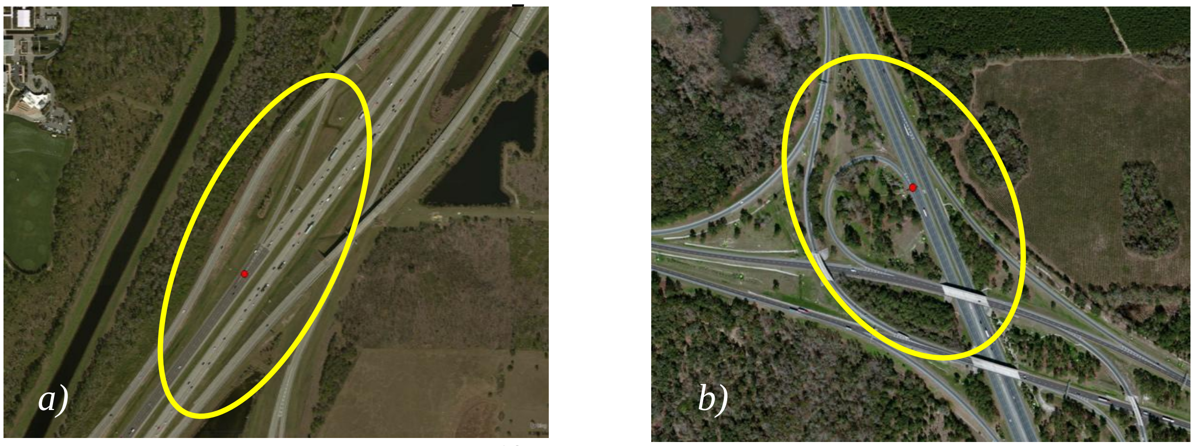

FIGURE 2 Examples of ramps with *a)* more and *b)* less favorable design characteristics.

RESULTS

Separate analyses (ANOVA) were carried out for driver performance before and after traversing the reference node at the ramp gore. It was hypothesized that reducing the demand for older drivers in negotiating freeway ramps would have a greater benefit for those with medical conditions than for those without medical conditions, narrowing differences between groups as reflected in measures of speed, acceleration, and number of brake applications. The criterion for significance was $p<.05$.

Table 7 presents the mean and standard deviation for each performance measure, under each combination of group by ramp design condition. The number of ramp traversals contributing to each comparison are shown, as well as the number of individual drivers in each group who made those traversals.

Before the node, there was a main effect of ramp design on maximum acceleration (higher for more favorable designs) ($F=27.99$; $df=1,89$); number of brake applications (more applications on less favorable designs) ($F=4.53$; $df=1,89$); and cumulative time headway >3.5 sec (more for less favorable designs) ($F=8.09$; $df= 1,89$). There was a single main effect of group: medical conditions drivers exhibited a significantly higher cumulative time headway >3.5 sec than drivers without medical conditions ($F=5.70$; $df=1,89$).

After the node, the only main effect was ramp design on maximum speed (higher for more favorable designs) ($F=5.37$; $df=1,89$). There were no significant group X ramp interactions, either before or after drivers passed the node at the tip of the gore.

DISCUSSION

When the performance of SHRP2 drivers aged 65 and older with and without medical conditions was compared in freeway merge situations, on ramp/acceleration lane geometries that were classified as ‘less favorable’ versus ‘more favorable’ by a road safety engineer, differences were hypothesized such that the medical conditions group would drive slower (maximum and average speed), with greater speed variance (more brake applications), and would allow longer headways to a lead vehicle. It was also hypothesized that reducing the demand for negotiating ramps through more favorable design would have a greater benefit for the older drivers *with* medical conditions than for drivers *without* medical conditions. While a number of reliable differences were found on these performance measures as a function of ramp design, the only hypothesis borne out regarding differences between groups was that medical conditions drivers exhibited a higher cumulative time headway ≥3.5 seconds than drivers without medical conditions, and only before reaching the ramp gore. There were no significant interactions (group-by-design).

It must be reiterated that none of these facilities represented a design deficiency in terms of current AASHTO standards. Some were simply more favorable than others with respect to the demands they placed on drivers for path following, gap maintenance, and the delicate dance of divided attention that describes negotiating a ramp’s curvature at speed, accelerating to match traffic on the mainline, and ensuring a safe headway to the vehicle ahead, all the while checking for gaps to merge into. In fact, the main effect of ramp design epitomizes what engineers refer to as the ‘operational effects of geometrics,’ and it serves as an important manipulation check for this analysis: driving task demand apparently did indeed vary from one set of ramps to the other.

One limitation in these analyses was the assignment to driver groups based on self-reports – drivers who were assigned to a particular medical condition made a checklist entry for that condition (and only that condition). Presumably, these entries reflected what drivers were told by their physicians; but it does not rule out the possibility of undiagnosed co-morbidities. Still, the group with self-reported medical conditions did not differ significantly from the control group on any of the available functional measures – visual acuity (bilateral), contrast sensitivity, rapid pace walk, Trail-making, Useful Field of View, and visual closure. This helps explain the absence, for almost all performance measures, of both a main effect of driver group, and a group-by-design interaction. It also reinforces the message that functional status, rather than medical diagnosis, is the proper focus in discussions of aging and safe driving.

There were additional limitations in this exploratory analysis. The driver samples were small, and they were self-selected based on their exposure to specific freeways/ramps in the Tampa/St. Petersburg, FL, area; there is no indication of the extent to which, more broadly, drivers with medical conditions avoid freeway driving, or may have avoided these specific junctions. Another consideration is the relative age of the drivers included in the control and medical conditions groups. While precise ages could not be obtained, the 5-year age group data indicate that medical conditions group drivers skewed younger than control group drivers in the present analysis sample. With the likelihood of impairment due to a medical condition increasing with increasing age, it is possible that between-group differences would have been amplified if both groups were matched in terms of the age of their members. Finally, no information was available concerning other, operational factors that could affect instantaneous driving task demand (e.g., weather conditions, density of traffic the driver was merging into on the freeway).

TABLE 7 Performance analysis results.

		Ramp Design	More Favorable		Less Favorable	
		Study Group*	Control (n = 20/135)	Medical Conds (n = 12/166)	Control (n=14/109)	Medical Conds (n = 11/75)
Before Node (15 sec)	Max Speed Before Node (mph)	Mean	54.64	56.46	58.86	56.96
		SD	7.64	6.01	9.02	5.20
	Mean Speed (mph)	Mean	30.15	41.18	38.88	44.64
		SD	19.49	15.96	20.38	13.45
	Maximum Longitudinal Acceleration (g)	Mean	0.09	0.11	0.05	0.06
		SD	0.05	0.05	0.03	0.03
	Maximum Longitudinal Deceleration (g)	Mean	-0.05	-0.06	-0.06	-0.05
		SD	0.03	0.04	0.03	0.02
	Number of Brake Applications	Mean	0.08	0.02	0.16	0.15
		SD	0.19	0.04	0.32	0.32
	Time to Headway > 3.5 sec (sec)	Mean	1.01	1.45	2.76	4.17
		SD	1.80	1.23	3.54	4.88
	Time to Headway < 3.5 sec (sec)	Mean	6.87	5.28	7.28	5.44
		SD	6.06	4.32	5.18	5.23
	Time to Lead Vehicle (sec)	Mean	7.88	6.73	10.05	9.61
		SD	5.44	3.70	3.79	4.47
	Mean Distance to Lead Vehicle (feet)	Mean	24.11	24.69	21.73	25.91
		SD	13.75	9.98	7.16	8.68
	Minimum Distance to Lead Vehicle (feet)	Mean	22.03	22.61	18.06	22.66
		SD	13.99	9.77	7.47	9.27
	Maximum Distance to Lead Vehicle (feet)	Mean	27.15	27.56	30.25	30.88
		SD	14.18	10.48	14.00	11.74
After Node (15 sec)	Max Speed Before Node (mph)	Mean	59.31	63.44	60.63	60.02
		SD	7.01	6.01	9.23	5.82
	Mean Speed (mph)	Mean	33.26	47.86	40.71	47.04
		SD	21.13	17.94	21.57	14.06
	Maximum Longitudinal Acceleration (g)	Mean	0.06	0.08	0.07	0.08
		SD	0.02	0.03	0.03	0.04
	Maximum Longitudinal Deceleration (g)	Mean	-0.05	-0.05	-0.06	-0.04
		SD	0.03	0.02	0.03	0.02
	Number of Brake Applications	Mean	0.09	0.15	0.21	0.06
		SD	0.19	0.27	0.60	0.12
	Time to Headway > 3.5 sec (sec)	Mean	3.05	1.08	2.63	2.06
		SD	4.40	0.93	1.74	2.05
	Time to Headway < 3.5 sec (sec)	Mean	7.63	6.58	6.57	7.15
		SD	5.56	3.09	4.75	4.25
	Time to Lead Vehicle (sec)	Mean	10.68	7.67	9.21	9.20
		SD	4.70	3.03	4.20	3.68
	Mean Distance to Lead Vehicle (feet)	Mean	24.31	22.17	21.94	24.04
		SD	12.52	7.68	9.83	7.50
	Minimum Distance to Lead Vehicle (feet)	Mean	19.86	16.87	16.53	17.58
		SD	12.17	7.36	10.55	9.37
	Maximum Distance to Lead Vehicle (feet)	Mean	31.97	31.15	33.66	35.00
		SD	13.17	9.59	11.45	9.31

*n = number of drivers in group who traversed ramps / total number of ramp traversals

On a positive note, these findings suggest that diagnosed medical conditions prevalent among older drivers need not, in and of themselves, connote performance (or safety) deficits if controlled such that age-normal function is preserved. And by extension, the almost complete absence of main effects of driver group on performance suggests that a higher prevalence of serious medical conditions among the older driving population does not necessarily limit the *mobility* of those so afflicted, compared to their peers who do not experience such conditions.

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REFERENCES

1. AASHTO (2011). *A Policy on Geometric Design of Highways and Streets, 6th Edition*. Washington, DC: American Association of State Highway and Transportation Officials.

2. American Medical Association, with the National Highway Traffic Safety Administration. *Physician's Guide to Assessing and Counseling Older Drivers* (revised 2010).

3. Brewer, M, Murillo, D, and Pate, A. (2014). *Handbook for Designing Roadways for the Aging Population.* Report No. FHWA-SA-14-015. Washington, DC: Federal Highway Administration.

4. Darren, T.J, Hutton, J.M., Bokenkroger, C.D., Harwood, D.W., Gilmore, D.K., Knoshaug, M.M., Ronchetto, J.J., Brewer, M.A., Fitzpatrick, K., Chrysler, S.T., and Jesse Stanley (2012). *NCHRP Report 730: Design Guidance for Freeway Mainline Ramp Terminals*. Washington, DC: Transportation Research Board.

5. Wim Van Winsum and Hans Godthel (1996). *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 38(3), 434-441.