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The Impact of Roadway Intersection Design on Driving Performance of Young and Senior Adults

Preliminary Results

Sherrilene Classen, PhD; Orit Shechtman, PhD; Burton Stephens, MA; Ethan Davis, BS; Roxanna Bendixen, MHS; Patricia Belchior, OT; Milapt Sandhu, MPT; Michael Justiss, MOT; Christina Posse, MHS; Dennis McCarthy, MEd; William Mann, PhD

The Federal Highway Administration (FHWA) proposed highway design guidelines to increase safe driving ability of older drivers, but little empirical evidence exists to support these guidelines. Using kinematics measures from an instrumented vehicle and on-road evaluations, the authors examined the safety effects of improved versus unimproved intersections in older (65–85) and younger (25–45) drivers. Kinematics measures showed that 4 maneuvers had significantly poorer lateral stability for the unimproved conditions, and significantly greater speed for the improved conditions. Behavioral measures showed that drivers had significantly fewer errors for 2 improved left-turn maneuvers, and fewer total errors overall, with older drivers having a higher mean number of errors. These findings suggested that the FHWA guidelines for safe road conditions result in safer driving by older and younger adults. **Key words:** *experimental design*, *improved intersections*, *instrumented vehicle*, *older drivers*, *on-the-road evaluation*, *repeated measures*, *roadway infrastructure*

From the Department of Occupational Therapy (Drs Classen, Shechtman, and Mann), PhD Program in Rehabilitation Science (Drs Classen, Shechtman, and Mann, Mss Bendixen, Belchior, and Posse, and Messrs Sandhu, Justiss, and McCarthy), National Older Driver Research and Training Center (Drs Classen, Shechtman, and Mann, Messrs Stephens and McCarthy), College of Public Health and Health Professions, University of Florida, Gainesville; and Department of Mechanical and Aerospace Engineering, College of Engineering, University of Florida, Gainesville (Mr Davis).

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Corresponding author: Sherrilene Classen, PhD, Department of Occupational Therapy, College of Public Health and Health Professions, University of Florida, Gainesville, FL 32611 (e-mail: oshechtm@phhp.ulf.edu).

BACKGROUND AND SIGNIFICANCE

The older population is the fastest growing segment of the American population. This group is living longer and driving longer.[1] Age-related changes and an increased likelihood of multiple, chronic diseases and medication use put this group at an increased risk for unsafe driving behaviors and crashes.[2,3] Clinical measures have not been reliable predictors of on-road driving performance, thus making identification of at-risk drivers difficult.[4,5] In addition, certain roadway intersection characteristics may be more problematic for older drivers, thereby increasing the risk of driving errors and crashes. The Federal Highway Administration (FHWA) proposed guidelines for highway design to increase the safe driving ability of older drivers, but little empirical evidence exists to support these guidelines.[6]

On the basis of previous crash data and observational studies,[7-11] we expected that improved intersections would generally fare better with a stronger effect for older drivers. In particular, we expected that lateral control stability would be improved during turning at intersections, although some effects would be expected as drivers approached the intersection or "recovered" having negotiated the intersection. Forward motion, measured with a longitudinal accelerometer and speed sensor, was expected to be greatest for subjects who exercised greatest "certainty" and control.

Figure 1. Example of Maneuver 2A: Improved intersection with higher speed roads with right-turn channelization at an intersection; an acceleration lane is present and sloping curbs are painted.

Purpose

Using on-road evaluations and kinematics measures from an instrumented vehicle, this study investigated the effects of improved versus unimproved intersections (turn-phase only) and determines if negotiation of these intersections is safer for both older (65–85 years) and younger (25–45) drivers.

METHODS

Sample

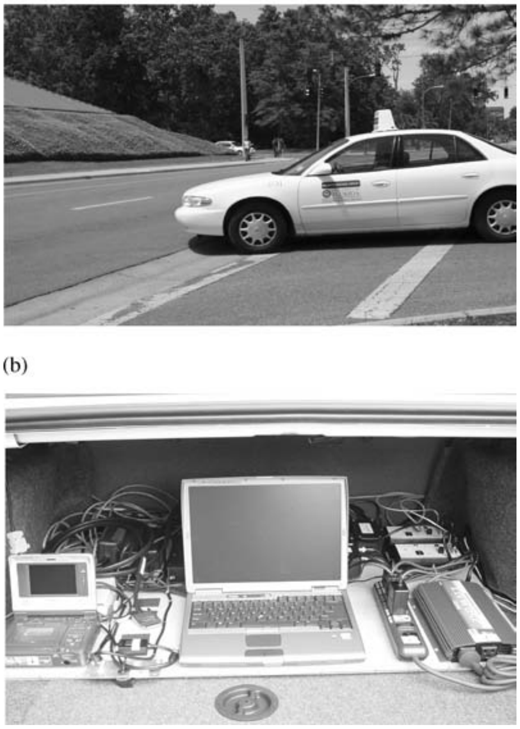
Participants who met our inclusion criteria were recruited from North Central Florida via paid advertisements in newspapers; flyers distributed to aging service centers (eg, Area Agency on Aging), health clubs, apartment complexes, community centers; open houses held at the University of Florida's Gator-Tech Smart House; and from word-of-mouth referrals. Approval of the research plan was obtained from the University of Florida's Institutional Review Board and all participants completed a telephone and informed consent form before enrolling in the study.

Design

The driving performance of old and young subjects through 5 pairs of intersections (improved versus unimproved) was examined using kinematics data as well as driving-evaluation (behavioral) data. The pairs of intersections, referred to as maneuvers in this report, included the presence and absence of the following conditions: Maneuver 1: extended receiving lane; Maneuver 2: higher speed roads with right turn channelization at an intersection; Maneuver 3: left turn offsets; Maneuver 4: signalized intersections with separate lane signals for each lane; and Maneuver 6: skewed angle intersecting roadways. Figure 1 presents an example of an intersection with an improved intersection and Figure 2 an unimproved intersection. The rationale for selection of intersection types for inclusion in on-road study is fully described and may be obtained from the primary author.

Figure 2. Example of Maneuver 2B: Unimproved intersection with higher speed roads with right-turn channelization at an intersection but with no acceleration lane; curbs are not painted.

(a)



(b)

Figure 3. (a) The instrumented vehicle used for on-road portion of study; (b) setup and recording devices in the trunk of the instrumented vehicle.

Procedure

The vehicle used for on-road evaluations was a 2004 Buick Century, a typical American car of the type that many older drivers use. It was instrumented to provide kinematics data that reflected control behavior of the driver. Figures 3(a) and 3(b) present the instrumented vehicle.

The road course consisted of an urban, suburban, and residential street network in Gainesville, Fla. On average, test subjects required slightly more than an hour to complete the course. Embedded in the course were 10 test intersections, 5 of which are referred to as *improved*, consistent with recommendations in the FHWA design guidelines for improving performance and safety of older drivers. The road course and maneuver locations, the rationale for inclusion of the specific test intersections, and diagrams of these intersection were obtained in cooperation with the Gainesville Traffic Engineering Department, Gainesville, Fla.

Measurement

Kinematics, or vehicle control responses, included yaw rates (radians/s), lateral (g forces), longitudinal (g forces), and combined (overall lateral and longitudinal control accelerations) (g forces) and speed (mph). Four cameras recorded the drivers' head movements and the forward and rear roadway scenes. Stability measures were obtained from a lateral accelerometer and a yaw rate sensor in the car during road tests, and were computed through algorithms using *Matlab* [computer program] Version 7.0.4, MathWorks, Inc; 1984–2005.

Behavioral data consisted of observed performance, expressed as error or error-free, through each of these intersections and included vehicle position, lane maintenance, speed, yielding, signaling, visual scanning, adjustment to stimuli/traffic signs, and gap acceptance (left turn only). Participant errors were scored and indicated with discrete continuous responses. Higher numbers indicated that more errors were made.

Data collection

Participants engaged in a telephone interview, brief clinical assessment, and an on-the-road driving assessment. All assessments were conducted by a trained evaluator using an instrumented vehicle. The trained driving evaluator, sitting in the passenger seat of the car, used a standardized road assessment performance sheet to record driving errors on a standardized driving road course. The interrater reliability among the evaluators was high (intraclass correlation coefficient = 0.80–1.00). Kinematics data were entered and managed using Matlab (Version 7.0.4) software, while behavioral data were entered and managed in a MS-Access database. All data were then imported and analyzed using MS-Excel, *SPSS for Windows* [computer program] Version

13.0.1. Chicago: SPSS Inc; 2005, and *SAS (r)* [computer program] Version 9. SAS Institute Inc Cary, NC; 1999.

Analyses

A power analysis with $\alpha = .05$ and $\beta = .80$ with a moderate effect size and attrition rate of 20% yielded a requirement of 109 participants. Although study enrollment is still ongoing, a preliminary analysis of 45 subjects was performed on subjects who completed all portions of the evaluation. The kinematics data included maximum yaw, lateral, longitudinal, and combined acceleration, as well as speed during the turn phase of maneuvering at each intersection. To test for the effect of age and road condition, the kinematics data were analyzed using a 2×2 repeated measures analysis of variance; the within-subject variable was intersection condition (improved vs unimproved) and the between-subject variable was age (young vs old). Behavioral data were expressed as the number of errors in each of the 5 maneuvers. Differences between errors made for the improved versus unimproved conditions were computed for each subject. The paired data for each maneuver were analyzed separately using Wilcoxon signed rank tests. To test for the effect of age (young versus old), the difference scores were analyzed using Wilcoxon rank sum test.

RESULTS

Preliminary results indicated significant findings between the improved and unimproved road conditions. Tables 1, 2, and 3 show that, for the kinematics measures, all the maneuvers had significantly greater maximum yaw, lateral acceleration, and combined

Table 1. Kinematics data of younger and older drivers during the turn phase of Maneuver 1 ($N = 45$ [$n_{young} = 26$, $n_{old} = 19$])

		Maximum combined acceleration (g)		Maximum longitudinal acceleration (g)		Maximum lateral acceleration (g)		Maximum yaw (radians/s)		Maximum speed (mph)	
Descriptive statistics											
Intersection	**Age**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Improved	Young	0.295	0.040	0.163	0.062	0.284	0.035	1.059	0.218	18.942	1.993
	Old	0.294	0.045	0.144	0.046	0.291	0.044	1.024	0.124	18.716	1.947
Unimproved	Young	0.329	0.050	0.158	0.065	0.323	0.052	1.258	0.151	15.696	2.008
	Old	0.310	0.075	0.150	0.062	0.304	0.069	1.320	0.234	14.837	2.879
Inferential statistics											
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Age group (older versus younger drivers)		0.661	.421	1.197	.280	0.248	.621	0.095	.760	0.939	.338
Intersection type (improved versus unimproved)		6.012	.018*	.001	.970	6.389	.012*	47.203	.001*	103.878	.001*
Interaction (age × intersection)		1.018	.319	0.157	.694	1.791	.188	1.817	.185	0.819	.370

*$P \leq .05$.

Table 2. Kinematics data of younger and older drivers during the turn phase of Maneuver 2 ($N = 45$ [$n_{young} = 26$, $n_{old} = 19$])

		Maximum combined acceleration (g)		Maximum longitudinal acceleration (g)		Maximum lateral acceleration (g)		Maximum yaw (radians/s)		Maximum speed (mph)	
Descriptive statistics											
Intersection	**Age**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Improved	Young	0.310	0.046	0.207	0.055	0.254	0.052	1.168	0.169	21.885	2.989
	Old	0.308	0.064	0.213	0.065	0.243	0.066	1.1498	0.218	20.647	3.382
Unimproved	Young	0.336	0.047	0.188	0.041	0.312	0.052	1.341	0.145	19.123	4.170
	Old	0.347	0.059	0.176	0.046	0.327	0.069	1.380	0.153	17.373	3.162
Inferential statistics											
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Age group (older versus younger drivers)		0.005	.942	1.197	.831	0.041	.840	0.080	.779	3.187	.081
Intersection type (improved versus unimproved)		8.962	.005*	11.881	.001*	33.504	.001*	28.889	.001*	22.427	.001*
Interaction (age × intersection)		0.109	.743	0.046	.315	1.137	.292	0.598	.443	0.161	.690

*$P \leq .05$.

Table 3. Kinematics data of younger and older drivers during the turn phase of Maneuver 4 ($N = 45$ [$n_{young} = 26$, $n_{old} = 19$])

		Maximum combined acceleration (g)		Maximum longitudinal acceleration (g)		Maximum lateral acceleration (g)		Maximum yaw (radians/s)		Maximum speed (mph)	
Descriptive statistics											
Intersection	**Age**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Improved	Young	0.326	0.057	0.200	0.059	0.317	0.057	1.344	0.266	17.042	3.991
	Old	0.345	0.060	0.187	0.049	0.335	0.065	1.275	0.166	17.942	3.444
Unimproved	Young	0.317	0.044	0.171	0.050	0.305	0.044	1.510	0.211	15.015	9.530
	Old	0.297	0.048	0.166	0.042	0.290	0.047	1.358	0.121	13.968	2.390
Inferential statistics											
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Age group (older versus younger drivers)		0.005	.946	0.595	.445	0.014	.908	4.357	.043*	0.004	.951
Intersection type (improved versus unimproved)		13.600	.001*	6.464	.015*	10.983	.002*	14.632	.001*	5.218	.027*
Interaction (age × intersection)		6.060	.018*	0.141	.709	3.963	.053	1.599	.213	0.549	.463

*$P \leq .05$.

Table 4. Kinematics data of younger and older drivers during the turn phase of Maneuver 3 ($N = 45$ [$n_{young} = 26$, $n_{old} = 19$])

		Maximum combined acceleration (g)		Maximum longitudinal acceleration (g)		Maximum lateral acceleration (g)		Maximum yaw (radians/s)		Maximum speed (mph)	
		Descriptive statistics									
Intersection	**Age**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Improved	Young	0.312	0.037	0.151	0.054	0.306	0.038	1.045	0.088	18.950	2.123
	Old	0.349	0.059	0.159	0.067	0.344	0.061	1.168	0.117	18.947	2.360
Unimproved	Young	0.317	0.051	0.143	0.045	0.313	0.051	0.981	0.010	19.780	2.563
	Old	0.331	0.056	0.166	0.048	0.326	0.056	1.050	0.113	19.421	2.461
		Inferential statistics									
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Age group (older versus younger drivers)		0.388	.055	1.707	.198	3.668	.062	13.567	.001*	0.082	.776
Intersection type (improved versus unimproved)		0.680	.414	0.003	.956	0.453	.504	28.830	.001*	3.703	.061
Interaction (age × intersection)		1.986	.166	0.530	.471*	2.254	.141	2.555	.117	0.277	.601

*$P \leq .05$.

Table 5. Kinematics data of younger and older drivers during the turn phase of Maneuver 6 ($N = 45$ [$n_{young} = 26$, $n_{old} = 19$])

		Maximum combined acceleration (g)		Maximum longitudinal acceleration (g)		Maximum lateral acceleration (g)		Maximum yaw (radians/s)		Maximum speed (mph)	
		Descriptive statistics									
Intersection	**Age**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Improved	Young	0.277	0.045	0.154	0.062	0.267	0.042	1.114	0.115	17.596	2.304
	Old	0.285	0.060	0.169	0.057	0.272	0.057	1.120	0.199	18.142	2.137
Unimproved	Young	0.377	0.069	0.166	0.029	0.373	0.069	1.664	0.255	18.138	1.597
	Old	0.354	0.074	0.160	0.046	0.349	0.074	1.650	0.280	17.374	1.700
		Inferential statistics									
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Age group (older versus younger drivers)		0.186	.668	0.595	.445	3.963	.053	0.006	.940	0.049	.826
Intersection type (improved versus unimproved)		85.852	.001*	0.040	.843	100.090	.001*	207.591	.001*	0.123	.728
Interaction (age × intersection)		2.783	.103	1.344	.253	2.480	.123	0.070	.792	4.121	.049*

*$P \leq .05$.

Table 6. Kinematics data of younger and older drivers during the turn phase of the 5 maneuvers ($N = 45$ [$n_{young} = 26$, $n_{old} = 19$])*

		Errors made on Maneuver 1		Errors made on Maneuver 2		Errors made on Maneuver 3		Errors made on Maneuver 4		Errors made on Maneuver 6		All errors	
Descriptive statistics													
Intersection	**Age**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Improved	Young	1.769	0.951	1.038	0.720	1.769	0.951	2.231	1.177	1.769	1.366	8.577	2.248
	Old	1.842	1.068	1.000	0.667	2.158	1.463	1.684	1.529	1.421	0.838	8.105	3.557
Unimproved	Young	2.308	1.158	0.885	0.909	1.769	1.142	1.692	1.225	2.039	1.182	8.692	2.963
	Old	2.789	1.273	1.474	0.905	2.211	1.357	1.789	1.228	2.421	1.71	10.68	3.267
All errors	Improved	1.800	0.991	1.022	0.690	1.933	1.195	2.000	1.348	1.622	1.173	8.378	2.847
	Unimproved	2.511	1.218	1.133	0.944	1.956	1.242	1.733	1.214	2.2	1.424	9.533	3.261
Inferential statistics													
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Age group (older versus younger drivers)		480	.323	507	.106	438.5	.981	496.5	.175	467	.489	525.5	.048†
Intersection type (improved versus unimproved)		203.5	.001†	38.5	.456	1.000	.987	−55.5	.362	132.5	.009†	131	.045†

*W indicates Wilcoxon statistic.
† $P < .05$.

acceleration for the unimproved conditions, and significantly greater speed for the improved conditions. Increased side forces indicate poorer lateral control or stability during the turn, whereas increased speed indicates greater control or confidence during turning. Table 4 shows significance in maximum yaw between older and younger drivers ($F = 3.567$; $P = .001$), as well as significance in maximum yaw between improved and unimproved intersections ($F = 28.830$; $P = .001$), with a smaller mean for older drivers on the unimproved intersection (*mean* = 1.050; *SD* = 0.113).

Interaction effects for maximum combined acceleration (age × intersection) were evident in Maneuver 4 ($F = 6.060$; $P = .018$), with both older and younger drivers doing poorer on the improved intersections. Interaction effects for maximum speed (age × intersection) were evident in Maneuver 6 ($F = 4.121$; $P = .049$), with older drivers maintaining a higher average speed on the improved conditions while younger drivers maintained a higher average speed on the unimproved conditions (Table 5). This maneuver, which requires a very sharp turn, presents an unusual geometric configuration in the Gainesville area and the interaction effect may be partially explained by the overcautious behavior among the older drivers and risk-taking behavior among the younger drivers.

Table 6 presents the behavioral measures, indicating that drivers had significantly less errors for 2 (Maneuver 1 and 6) of the improved left-turn maneuvers (Maneuver 1: *Wilcoxon* 203.5; $P = .001$; Maneuver 6: *Wilcoxon* 32.5; $P = .009$). Drivers committed less errors on the improved intersections (*Wilcoxon* 131; $P = .048$) and a significant difference was detected for age (*Wilcoxon* 525.5; $P = .048$), with the older drivers committing more errors than younger drivers.

DISCUSSION

The results of the kinematics data indicate that, in general, driving through the improved intersections produced less force on the car as it was making the turn, resulting in drivers negotiating improved intersections with greater speed. Compared to the unimproved intersections, the behavioral data indicate that drivers made fewer *total* errors on all the improved intersections; and comparing each intersection to one another, drivers made fewer errors on 2 of the improved intersections. These data also showed that older drivers made more total errors than younger drivers on the unimproved intersections.

These preliminary findings suggested that the FHWA guidelines for implementing safe road conditions are helpful for safer driving. Overall, it seemed that young and older adult participants, alike, may benefit from roadways with these safety features, yielding critical information for engineers, planners, policymakers, and others involved in the design of roadway systems to enhance safe driving.

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