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N. Teasdale and R. Wade Allen

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# Training the older driver

R. W. Allen[1] N. Teasdale[2]

[1] *Systems Technology, Inc.*
*email: rwallen@systemstech.com*
[2] *Université Laval*
*email: Normand.Teasdale@kin.msp.ulaval.ca*

**Abstract**

This special issue reports on papers presented at a simulation user group meeting on Training the Older Driver held at Université Laval in Québec, Canada. The meeting attracted a little more than 50 attendees from 5 different countries.
This special issue includes six papers covering a wide range of research topics. The first paper considers the relationship between intersection design and simulated driving performance shows the increasing role of virtual environment for testing and improving roadway design. This is a topic of utmost interest that will contribute to increasing road safety in the future. Two papers address the important issue of how dual-task demands can challenge driving performance which is an important topic for road safety considering the ever increasing number and complexity of in-vehicle devices. The association between heart rate reactivity and driving performance under dual task demands in late middle age drivers describes a sensitive measure of driving stress. Another paper takes a novel look into the use of a driving simulator to study eyewitness accuracy. Finally, a paper describes the challenge TBI (traumatic brain injury) patients find in the driving environment.

## 1. Introduction

This is the fifth special issue devoted to driving simulation research and application concerning driver behavior and transportation system safety. The first special issue in 2004 resulted from papers given at a conference in San Diego, California, USA [1].

The theme of the first conference was “New Directions in Driving Simulation Research.” Three more symposia have been held and reported on in the last three years:

“Multidisciplinary new approaches to old problems: an overview of driving simulation research” held in Stuttgart, Germany in September 2005 [2];

“New approaches to simulation and the older operator” held at the Massachusetts Institute of Technology in October of 2006 22[3]; and

“Application of driving simulation to road safety,” [4] held in Rome in 2007 as an adjunct to the Road Safety and Simulation 2007 conference [5]. For this meeting, the diversity of the research was remarkable and speaks out for the increasing role of simulation in studying road safety. Two keynote speakers (Elin Schold-Davis, head of the American Occupational Therapy Association's Older Driver Initiative; Michel Bédard, Canada Research Chair in Aging and Health, Lakehead University) addressed the implication of simulators for training and rehabilitation of the older driver. Several presentations also addressed this important issue.

Other categories of drivers were also considered. As an example, Arvid Harmsen (A&A bv) nicely presented the controversial consequences of the EU directive for initial qualification and periodic training of professional truck drivers [7] and Wade Allen (Systems Technology Inc.) presented data from a longitudinal study showing how simulator training can reduce the number of accidents in novice drivers (e.g. [8]). The contribution and use of the simulator for pharmacological research and cognitive based research was featured in several presentations as well. More technical presentations aimed at improving the virtual environment or developing scenarios contributed to the diversity and quality of the meeting; an Excel-based programming tool (Bruce Weaver, Lakehead University), implementing an analog speedometer in STISIM Drive (Jean-François Tessier, Université Laval) and the clever technique for developing roundabout scenarios (Steve Markham, Valentine Technologies Ltd) all captured the interest of attendees. Although not all presentations are part of this special issue, proceedings of the meeting and Power Point presentations are available on request [6].

## 2. Contributions

*"The impact of roadway intersection design on simulated driving performance of younger and older adults during recovery from a turn"*

This paper describes a study of older driver reaction to intersection design using a high fidelity simulator. Specifically whether improved design features as recommended by the US Federal Highway Administration are effective during recovery from a turn in 4 pairs of intersections involving unimproved versus improved designs. The results showed that one of the intersections benefitted from the design improvements, and that the improvement was equivalent for both younger and older drivers. However, younger drivers did exhibit higher speeds during the recovery phase of three left turn intersections. The findings of the present study may provide critical information for enhancing safe driving to those involved in roadway design, such as engineers, planners, and policy makers.

*"The initial development of a low-cost method for predicting the disruption of glances towards in-vehicle information systems"*

This paper describes an important technique for evaluating automotive displays in terms of their distraction value. This evaluation technique is particularly relevant with the trend towards sophisticated in-vehicle information systems (IVIS). This is a relevant example of the application of driving simulation for evaluating potential driver risk in connection with new in-vehicle technology.

*"Older driver performance on a simulator: associations between simulated tasks and cognition"*

This study considers the relationship between standard cognitive tasks and driving and whether performance on different driving tasks is correlated. The results indicate there was little correlation in performance among driving tasks, suggesting that they involve independent skill sets. This result highlights the importance of assessing seniors' performance on a range of driving tasks. Cognitive task performance was also predictive of driving task performance. The lack of correlation in performance among the three driving tasks, and the correlations found between different cognitive tests and the driving tasks, suggest that the driving tasks involve different driving abilities and cognitive constructs. This adds further evidence to the extant literature in support of researchers' and driving evaluators' use of a range of performance and driving tasks that assess different driving domains.

*"The use of a driving simulator to study eyewitness accuracy for three different types of collision"*

This is a fairly unique application of simulation to investigate the reliability of eye witness testimony regarding vehicle collisions. Despite high self reported confidence ratings the results indicated that recall was poor, although recall was better for collisions where the drivers and passengers were directly involved. No significant recall differences were found between drivers and passengers, but recall was better for collisions where the driver and passengers were directly involved as opposed to situations involving other vehicles. Also, heart rate was higher for collisions where the participants were directly involved suggesting that arousal may improve recall of traffic events. This simulator application may have bearing on the forensic analysis of traffic incidents.

*"The association between heart rate reactivity and driving performance under dual task demands in late middle age drivers"*

In this study heart rate responses were compared during a variety of dual task conditions along with driving and task performance data. During two of the tasks in which younger participants showed significant heart rate acceleration, older drivers, as a group, showed little or no change in heart rate. During a portion of the simulation consisting of highway driving, a continuous performance task (CPT) was presented as a secondary task to increase workload. Heart rate response did not correlate with performance on the CPT in the younger subjects. In the older subjects, however, the heart rate acceleration group scored significantly higher on the CPT than those who did not exhibit a pattern of heart rate acceleration. In addition to lower performance on the CPT task, older adults in the non-acceleration group showed a significant drop in driving speed, which is generally interpreted as a compensatory response employed to manage total workload. This study shows the utility of including psychophysiological response as a measurement and looking for responses under dual task conditions.

*"Examination of traumatic brain injured drivers' behavioural reactions to simulated complex roadway events"*

This study examines the behavioural reactions of highly functional TBI (Traumatic Brain Injury) drivers in response to simulated driving obstacles in comparison to matched controls. Both tactical and operational levels of driver behaviour were investigated. Longitudinal acceleration, longitudinal velocity, lateral velocity and lane position were recorded during four separate surprising encounters with road obstacles for both TBI patients and normal controls. Results indicated that TBIs were slower to respond, swerved less, and were more cautious immediately after the obstacle had passed. TBI drivers also drove slower overall. Because of the potential driving risk incurred by TBI patients, this paper provides a potential useful simulator assessment example which might also apply to other at risk clinical populations.

*"A novice driver transfer of training experiment"*

Fidelity and validity are critical issues in the application of driving simulators. This paper presents a study that represents one form of validation that is appropriate for training simulators. The study concludes that simulator training with higher fidelity simulators can reduce novice driver crash rates.

*"Implementing an analog speedometer in STISIM Drive using Parallax BSTAMP microcontroller"*

This paper describes the integration of a physical speedometer into a simulation using a microcontroller. This simple, low cost approach provides a more realistic instrument panel and provides better integrations with other actual instruments and controls.

## 3. Summary

There are a range of useful driving simulator applications that relate to roadway safety. These applications all have the common advantage that they can investigate hazardous driving conditions in the safety of a simulated driving environment. Hazards and risks can arise due to many factors associated with the driver, vehicle and roadway environment. The logistics of studying these circumstances in real world, behind the wheel driving can be difficult if not impossible. In the case of roadway designs, the desired conditions may not exist in the real world, but can be created in the simulation virtual world. This is also true of vehicle designs including advanced in-vehicle systems that may make demands on the driver's attention. Finally, various driver conditions including a range of impairments that increase risk of crashes cannot be tested safely in the real world. The capability of simulation to produce realistic virtual worlds is continually expanding, and the cost of achieving these conditions is continually falling, and therefore the application of driving simulation is becoming more appealing to a wide range of researchers in various disciplines. We see this trend continuing in the near future.

## Acknowledgements

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# The impact of roadway intersection design on simulated driving performance of younger and older adults during recovery from a turn

O. Shechtman[1,2] S. Classen[1,2] B. Stephens[2] E. Davis[3]
K. Awadzi[1,2] W. Mann[1,2]

[1]*Institution1Department of Occupational Therapy, College of Public Health and Health Professions, University of Florida, PO Box 100164, 101 South Newell Drive, Gainesville, Fl, 32611*
[2]*National Older Driver Research and Training Center, College of Public Health and Health Professions, University of Florida*
[3]*Department of Mechanical and Aerospace Engineering, College of Engineering, University of Florida, PO Box 116250, Gainesville, FL 32611-6250.*
*e mail: oshectm@phhp.ufl.edu*

**Abstract**

Objective**:** The Federal Highway Administration (FHWA) proposed guidelines for highway design to increase the safe driving ability of older drivers. Little empirical evidence exists to support the effectiveness of these guidelines. The purpose of this study was to investigate if the improved design features are effective during recovery from a turn in 4 pairs of intersections using a high-fidelity driving simulator.
Methods**:** Using the FHWA guidelines, we replicated four pairs of improved versus unimproved intersection in a driving simulator. We examined driving performance, as indicated by kinematic measures, of younger (25-45 years) and older (65-85 years) drivers during recovery from a turn in four intersection pairs. Thirty-nine subjects, 19 young and 20 older adults, participated in the study. Kinematic measures were obtained from the simulator and analyzed for differences.
Results: Our findings indicated that the FHWA guidelines for implementing safe road conditions were helpful in one of the four improved intersections for both younger and older drivers. We also found that older drivers did not benefit more or less than younger drivers from implementing the FHWA guidelines. Finally, younger drivers exhibited higher speeds during the recovery phase of the three left-turn intersections.
Conclusions**:** These findings suggest that both young and older drivers may benefit from some of the safety features recommended by the FHWA guidelines. The findings of the present study may provide critical information for enhancing safe driving to those involved in roadway design, such as engineers, planners, and policy makers.

*Keywords – Older and younger drivers, driving simulation, driving kinematics, roadway infrastructure, highway safety, intersection design*

## 1. Introduction

People age 65-years and older are living longer and driving longer [1,2]. Age-related changes, multiple chronic diseases, medications, and frailty put the older driver at an increased risk for unsafe driving behaviors and crashes [3-6]. Although driving rehabilitation specialists perform on-the-road evaluations to assess the safe driving ability of people medically at risk [7], these assessment are costly, time consuming, and at times risky, depending on the client's condition (e.g., legal blindness or Alzheimer's disease) [8].

Driving simulators, provide an alternative to on-road evaluation. They vary in cost, size and realism, using computer-based technology to create an impression that one is driving a vehicle. A driving simulator affords opportunities for high risk groups to be tested under safe, well-controlled, and repeatable conditions, in which errors can be made without cost to life, health or property [9,10].

However, some people experience simulator sickness symptoms when "driving" a simulator [11]. Simulator sickness is a type of motion sickness exhibited by persons in a flying or driving simulator due to illusionary motion, which is also called vection. The symptoms may include one or more of the following: pallor, dizziness, headache, cold sweating, eyestrain, nausea and vomiting [12,13].

## 2. Background

Various methods have been used to assess driving safety in research studies. These methods include recording driving errors during a driving assessment [7], examining crash rates, [2,3,14], self reports of drivers [15], or use of models that incorporate driver characteristics, roadway elements, vehicle design parameters and combinations of these factors [16].

The Federal Highway Administration (FHWA) proposed guidelines for highway design to increase the safe driving ability of older drivers [17]. Two studies evaluated the effectiveness of the FHWA guidelines by comparing improved intersections (with the recommended safety features) to unimproved intersections (without those safety features), both on the road [18] and in a simulator [19]. In these studies, driving safety was evaluated by examining driving performance as indicated by both kinematic measures and behavioral measures (driving errors). The driving errors were recorded on a standard sheet by trained driving evaluators who were sitting in the car cab during both driving and simulated driving.

For the kinematic data analysis, the vehicle's movement through an intersection was divided into three phases: approach, turn, and recovery [18,19]. These three phases were determined by a change in yaw (the rate of turn of a vehicle expressed in radians per second). As the vehicle begins to turn, the value of yaw increases and when the vehicle finishes the turn, the value of yaw returns to a value near zero.

Thus, the beginning of the turn phase/end of the approach phase was considered to be the moment in time in which the absolute value of yaw exceeded 0.05 radians/sec. Similarly, the end of the turn phase/beginning of the recovery phase was determined to be the moment in time when the absolute value of yaw fell below 0.05 radians/sec.

These previous studies [18,19] evaluated driving performance during the turn phase of the improved and unimproved intersections. The kinematic measures for the turn phase consisted of maximum yaw, lateral acceleration, and speed [18,19]. Maximum and average values are central tendency measures [20]. These measures were used for the turn phase because they offer insight into the overall control of the vehicle. The yaw values demonstrate how quickly the vehicle turns and the speed indicates how quickly it travelled through the intersection. Both yaw and lateral acceleration point to the amount of lateral stability of the vehicle. Lower lateral forces indicate greater control and stability of the vehicle, whereas greater speed during the turn phase demonstrates increased driver's confidence.

The results of these studies [18,19] indicated that in general, the turn phase of the improved intersections yielded greater vehicle stability and enhanced driver's confidence when compared to the unimproved intersections and that younger drivers exhibited more stability and confidence than older drivers.

**3. Purpose and hypotheses**

After making a turn drivers are expected to recover, i.e., regain steady state lateral control and increase speed according to the road conditions. The purpose of this study was to examine the differences in simulated driving performance (as indicated by kinematic measures) between younger (25-45 years) and older (65-85 years) drivers during the recovery phase of improved versus unimproved intersections.

Using the FHWA guidelines [17], we examined driving performance during the recovery phase in four pairs of improved versus unimproved intersections. The improved intersections contained the following features:

1) extended receiving lane,
2) right turn with channelization,
3) left-turn offset and
4) separate lane signals with protected left turn phase.

The unimproved intersections were similar geometrically, but did not have these enhanced roadway features. We also examined the differences in driving performance between younger drivers (25-45 years of age) and older drivers (65 to 85 years of age). Driving performance was inferred from kinematic measures and assumed to represent driving safety.

The present study examined the kinematic measures during the recovery phase of the same intersections as in the studies by [18] and [19]. During the recovery phase, the magnitude of yaw and lateral acceleration are very low because the vehicle's path is practically linear. Therefore, during the recovery phase, variability measures such as variance and root mean square (RMS), which represent the vehicle's deviation from its expected linear path, are more indicative of lateral stability. Higher values of variance and RMS of yaw and lateral acceleration indicate that the vehicle is deviating more from its linear path and that it is less stable.

Effective recovery is indicated by vehicle stability and by driver's confidence. Stability is inversely related to variability measures (variance and RMS) of both yaw and lateral acceleration. When comparing improved to unimproved intersections, we expect the recovery phase of the improved intersection to show less variability of lateral forces and thus greater stability. Driver's confidence during the recovery phase is related to resuming the speed appropriate for the road condition [21]. We expect average speed to be faster in the recovery phase of the improved intersections indicating that driver's confidence is greater when compared to the unimproved intersections. In addition, we expect forward acceleration to be inversely related to driver's confidence when the appropriate speeds are similar. The more the driver decelerates during the turn, the greater the forward acceleration would be during recovery because the driver has to accelerate more to achieve the appropriate speed [22]. Thus, greater forward acceleration (given similar speeds) during the recovery phase indicates poorer driving performance and forward acceleration values in the improved intersections are expect to be smaller.

Older drivers tend to decelerate or stop at intersections, resulting in slower speed and more rapid acceleration during recovery [22]. Older drivers also tend to perform more corrections during a turn, resulting in greater lateral forces and greater deviation from a linear path. Thus, for the age comparison of the recovery phase from both improved and unimproved intersections, we expect older drivers to exhibit greater variability of lateral forces indicating more deviation from a linear path. We also expect older drivers to drive at slower speed indicating less driver's confidence and more drivers' caution. We do not expect older drivers to exhibit greater forward acceleration because we expect the younger drivers to drive at faster speeds. When speed is not similar between the groups that are being compared, i.e., if younger drivers exhibit faster speeds than older drivers, then their forward acceleration is also expected to be greater.

We hypothesized that during the recovery phase at the improved intersections the kinematic performance of the simulator vehicle would exhibit: 1) lower variance and RMS of yaw and lateral acceleration, indicating less deviation from the linear path of travel and thus greater vehicle stability, and 2) higher speed and lower forward acceleration, indicating greater driver's confidence. Conversely, we expect the recovery phase at the unimproved intersections to be more erratic resulting in higher and more variable values of yaw and lateral acceleration, lower speeds, and higher forward acceleration. Likewise, we expect older drivers to exhibit lower variance and RMS of yaw and lateral acceleration as well as lower speeds as compared to younger drivers.

The four improved intersections are described below. The unimproved intersections did not include these improved features.

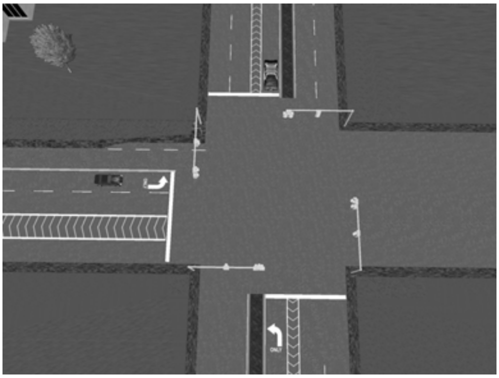
*Maneuver 1: Extended Receiving Lane* - The extended receiving lane allows drivers to make a larger radius turn, which should increase the lateral stability of the vehicle, thus allowing the turn-phase to be driven at a higher speed. Negotiating the $90^0$ tighter turn (unimproved intersection) requires the driver to reduce speed and/or increase the muscular effort of turning the wheel. Older drivers may experience increased difficulty when making tighter turns, which could result in less rotation of the steering wheel [23] causing greater positional errors during the turn. This would require more corrections during the subsequent recovery, resulting in greater deviation from a linear path as well as lower speed.

*Maneuver 2: Right Turn with Channelization and Acceleration Lane* – The combination of right turn channelization and an acceleration lane functions to allow drivers to merge into the intersecting road safely by reducing variance in roadway speeds between the merging vehicle and the approaching vehicles [22]. During the turn phase the presence of channelization allows for a more gradual turn, which should produce less yaw and lateral acceleration and thus allow drivers to resume higher speeds. For the recovery phase, drivers emerging from the acceleration lane are expected to have lower lateral forces, less deviation from a linear path, and higher speeds, in order to better match the speeds with approaching vehicles.

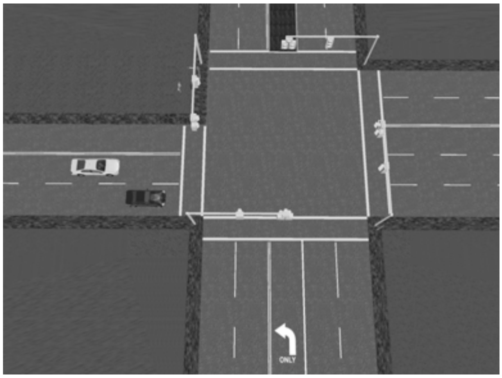
*Maneuver 3: Left-Turn Offset* - This feature is intended to increase the sight distance of drivers and improve gap acceptance judgment. This gain can occur only when the green ball phase is active or when the signal changes from green to yellow (but not when the green arrow is active). This feature is intended to benefit older drivers because their gap acceptance abilities tend to be poorer than younger drivers [22]. Increased sight distance may also increase driver's confidence, resulting in smoother and faster recovery.

*Maneuver 4: Separate Lane Signals with Protected Left Turn (PLT) Phase* - The use of separate lanes is intended to increase both safety and the number of vehicles the can pass through an intersection. The protected left-turn (PLT) signal phase reduces the need to make gap acceptance judgments about when to turn. It should therefore reduce the magnitude of acceleration required during the turn [22]. Thus, the recovery phase is expected to exhibit greater lateral stability and faster speed.

Figures 1-4 show screen shots of the improved (a) and unimproved (b) intersections while Table 1 provides the lane width for each intersection.

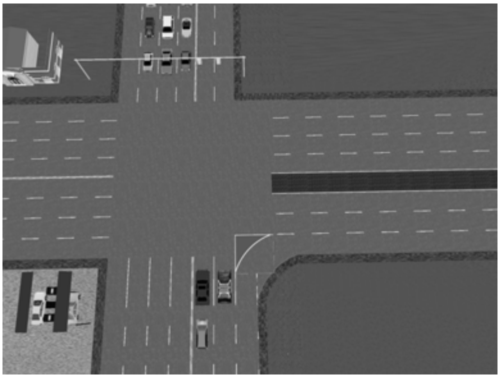


1 a = improved intersection

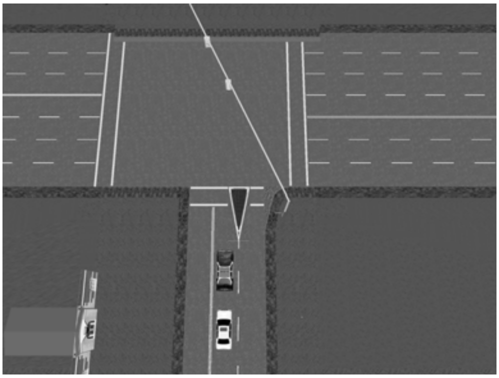


1 b = unimproved intersection

Fig. 1 - Maneuver 1

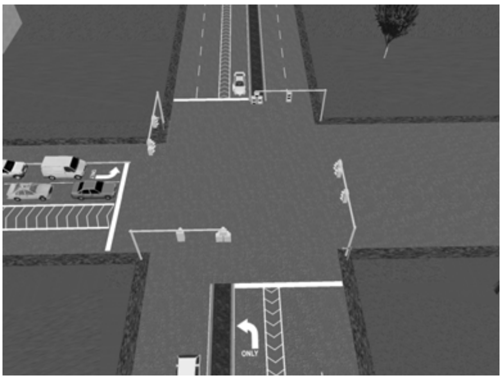


2 a = improved intersection

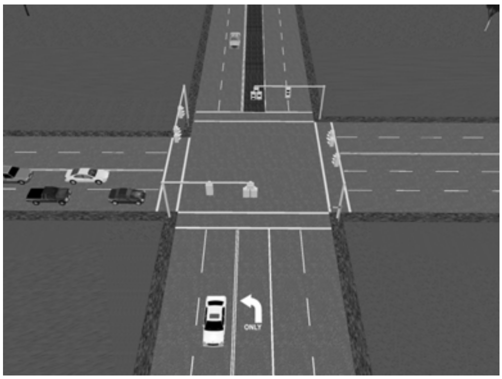


2 b = unimproved intersection

Fig. 2 - Maneuver 2

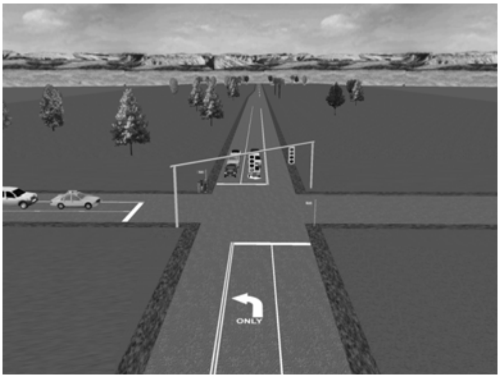


3 a = improved intersection



3 b = unimproved intersection

Fig. 3 - Maneuver 3


4 a = improved intersection

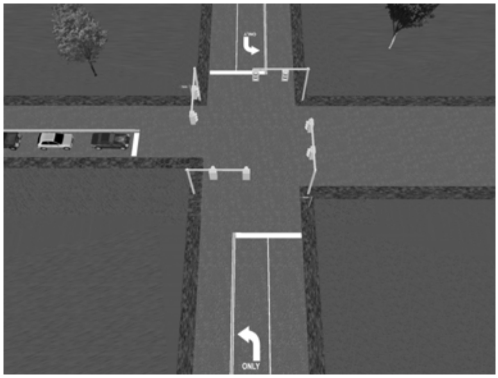

4 b = unimproved intersection

Fig. 4 - Maneuver 4

Tab. 1 - Specific intersection geometrics:
width of pre-intersection and post-intersection lanes and traffic flow of oncoming traffic

| Scenario | Width of Pre-Intersection Lane (ft) | Width of Post-Intersection Lane (ft) | Oncoming Traffic (Number of cars) |
|---|---|---|---|
| 1a | 12 | 16 | 5 |
| 1b | 12 | 12 | 6 |
| 2a | 12 | 12 | None |
| 2b | 12 | 12 | None |
| 3a | 12 | 12 | 7 |
| 3b | 12 | 24 | 7 |
| 4a | 12 | 12 | Stopped at signal |
| 4b | 12 | 12 | 8 |

## 4. Methods and materials

### *4.1. Sample*

Participants were recruited from the National Older Driver Research and Training Center's (NODRTC) recruitment pool. Inclusion and exclusion criteria are fully described in previous articles by these authors [18, 19]. All participants who met the inclusion criteria completed a telephone survey and informed consent forms before enrolling in the study. Approval of the research plan was obtained from the University of Florida's Institutional Review Board. A total of 39 subjects participated in the study, 19 younger subjects (33.26 $\pm$ 5.74 years of age) and 20 older subjects (73.65 $\pm$ 5.73 years of age). However, the gender distribution of these groups was skewed; the young group had 13 (68%) females and 6 (32%) males and the old group had 2 (10%) females and 18 (90%) males.

### *4.2. Design*

Four improved vs. unimproved intersections were replicated in a high fidelity driving simulator as previously described [19]. The simulator controls were integrated with an actual vehicle to make the driving experience as realistic as possible.

The pairs of intersections (maneuvers) included the presence and absence of safety features recommended by the FHWA guidelines [17] and were described in the introduction. The driving performance of old and young participants through four pairs of intersections was examined using kinematics data generated by the simulator's computer.

### *4.3. Procedure*

Subjects participated in a phone interview and underwent visual acuity and other clinical tests (Mini Mental State Examination [24] Trail making Test, Part B [25] to determine their eligibility to participate in the study. These clinical tests are fully described in earlier articles [18, 19].The participants also went through a standardized road course evaluation. On a different day, the participants completed the simulated road course evaluation. Some of the participants (28%) who met all inclusion criteria did not complete the simulated road course evaluation because they experienced simulator sickness symptoms [11].

We used a driving simulator that provided visual representations of real intersections located in Gainesville, Florida (a detailed description of the *On-Road Maneuver Locations Developed for Simulator Tests* may be obtained from the first author). This simulated road course replicated road geometrics and traffic control devices from an actual road course consisting of urban, suburban and residential street networks [26]. Prior to driving in the simulator, participants were screened for simulator sickness and then subjected to an acclimation period in the simulator. After driving the acclimation scenario (which provided a less complex visual representation of the road environment), participants drove the actual simulated road course (the main test scenario with the four pairs of test intersections), for a duration of approximately 15 minutes.

### *4.4. Data Collection and Measurement*

The simulator's computer generated kinematic data during the simulated drive. For the analysis used only the following kinematic data: RMS and variance of yaw (radians/sec) and lateral acceleration (g's); average forward acceleration (g's); and average speed (mph). Only data from the recovery phase were reported in this study. The recovery phase lasted from the end of the turn phase, when the absolute value of yaw fell below 0.05 radians/sec, to 500 feet beyond the intersection. Additional measures and traffic conditions that were automatically recorded during trials but not reported in the present study included: elapsed time from the beginning of run, total distance traveled from the beginning of the run, lateral lane position with respect to the roadway dividing line, vehicle heading angle (degrees), steering wheel angle input, brake actuation, driver signalizing, status of traffic signals, other roadway traffic, and collisions with other vehicles and pedestrians. In addition, data from the telephone interview, clinical assessments, and simulator sickness profiles were entered into a Microsoft Access database or Microsoft Excel spreadsheet. Trained driving evaluators, sitting in the passenger seat of the simulator's car collected behavioral data using a standardized road assessment performance sheet [27] to record driving errors. The assessment sheet was designed specifically for the simulated road course. The results from these data are reported in a previous manuscript [19].

### *4.5. Data Analysis*

The kinematic data were computed through algorithms using the Matlab software program (Version 7.0.4), imported and managed in MS-Excel, and analyzed using SPSS 13.0.1. The kinematic data were analyzed separately for each maneuver using a 2X2 repeated measures ANOVA; the within-subject variable was intersection (improved vs. unimproved) and the between-subject variable was age (young vs. old).

## 5. Results

*Maneuver 1: Extended Receiving Lane* – Significant main effects for both intersection and age were found for some of the variables, while no significant interactions were observed (Table 2). Unexpectedly, we found less lateral stability for the improved intersection, as suggested by the significantly greater RMS and variance of yaw, indicating greater deviation from a linear path during recovery than for the unimproved intersection. The differences for age were as expected, with older drivers exhibiting less lateral control of the vehicle as expressed by the significantly greater RMS of yaw as compared to younger drivers. In addition, older drivers showed less confidence (or more caution) as expressed by the significantly lower average speed. A graphic representation of an individual driver's raw kinematics data in the improved versus unimproved intersection is shown in Figure 5.

*Maneuver 2: Right Turn with Channelization and Acceleration Lane* – None of the main effects (intersection and age) or interactions were significant (Table 3). These findings suggest that in this right-turn intersection-pair, there were no differences in lateral stability and confidence between older and younger drivers in the recovery phase of both improved and unimproved intersections.

*Maneuver 3: Left-Turn Offset* – Significant intersection and age main effects were found for some of the variables, while the interactions were not significant (Table 4). As expected, drivers showed better lateral control at the improved intersection with significantly smaller variance and RMS yaw values. Also, as expected, older drivers exhibited less confidence and more caution as indicated by significantly smaller average speed and average forward acceleration values as compared to the younger drivers.

*Maneuver 4: Separate Lane Signals with Protected Left Turn (PLT) Phase* – There were no significant main effects for intersection and no significant interactions. However, some of the variables showed significant main effects for age (Table 5). Predictably, older drivers exhibited less confidence and more caution as indicated by significantly smaller average speeds. There were no differences in lateral stability between the age groups.

Tab. 2 – Kinematics data of younger and older drivers during the recovery phase of maneuver 1A & 1B; N = 39 ($n_{young}$ = 19, $n_{old}$ = 20)

| | | RMS Yaw (radians/sec) $*10^{-2}$ | | Variance Yaw (radians/second) $*10^{-4}$ | | RMS Lateral Acceleration (g) $*10^{-2}$ | | Variance Lateral Acceleration (g) $*10^{-4}$ | | Average Speed (mph) | | Average Forward Acceleration (g) $*10^{-2}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Descriptive Statistics | | | | | | | | | | | | | |
| **Intersection** | **Age** | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD |
| **Improved** | Young | 1.6 | 1.0 | 3.4 | 4.4 | 1.6 | 1.2 | 3.9 | 5.3 | 26.1 | 5.7 | 9.0 | 3.6 |
| | Old | 2.3 | 1.5 | 7.1 | 10.1 | 2.1 | 1.5 | 6.5 | 9.9 | 20.8 | 4.8 | 5.3 | 4.1 |
| **Unimproved** | Young | 1.3 | 0.5 | 1.9 | 1.8 | 1.3 | 0.7 | 2.1 | 2.5 | 26.3 | 5.6 | 9.0 | 4.4 |
| | Old | 1.7 | 0.6 | 3.1 | 2.3 | 2.5 | 4.1 | 22.0 | 83.1 | 22.3 | 5.2 | 6.3 | 3.7 |
| Inferential Statistics | | | | | | | | | | | | | |
| | | F | p | F | p | F | p | F | p | F | p | F | p |
| **Intersection Type (Improved versus Unimproved)** | | 5.01 | 0.03 * | 4.60 | 0.04 * | 0.01 | 0.94 | 0.48 | 0.49 | 1.25 | 0.27 | 0.58 | 0.45 |
| **Age Group (Older Versus Younger Drivers)** | | 5.57 | 0.02 * | 3.60 | 0.06 | 2.78 | 0.10 | 1.41 | 0.24 | 9.17 | 0.01 * | 8.33 | 0.01 * |
| **Interaction (Age x Intersection)** | | 0.32 | 0.57 | 0.87 | 0.35 | 0.56 | 0.46 | 0.78 | 0.38 | 0.72 | 0.40 | 0.68 | 0.41 |

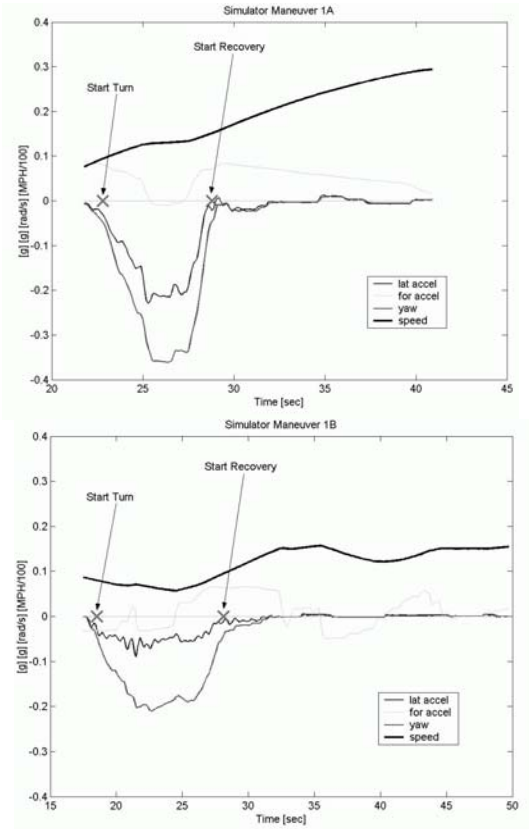



Fig. 5 - Example of the raw kinematics data (lateral and forward acceleration, yaw and speed) of one subject for maneuver 1 (improved vs. unimproved intersections)

Tab. 3 - Kinematics data of younger and older drivers during the recovery phase of maneuver 2A & 2B; N = 39 ($n_{young}$ = 19, $n_{old}$ = 20)

| | | RMS Yaw (radians/sec) $*10^{-2}$ | | Variance Yaw (radians/second) $*10^{-4}$ | | RMS Lateral Acceleration (g) $*10^{-2}$ | | Variance Lateral Acceleration (g) $*10^{-4}$ | | Average Speed (mph) | | Average Forward Acceleration (g) $*10^{-2}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Descriptive Statistics | | | | | | | | | | | | | |
| **Intersection** | **Age** | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD |
| **Improved** | Young | 3.2 | 2.5 | 14.6 | 27.4 | 3.0 | 1.8 | 12.0 | 14.7 | 25.1 | 7.2 | 9.2 | 5.6 |
| | Old | 1.9 | 0.8 | 4.4 | 3.5 | 2.2 | 1.4 | 6.9 | 11.5 | 22.4 | 5.0 | 5.9 | 4.7 |
| **Unimproved** | Young | 2.7 | 3.0 | 13.7 | 36.4 | 2.7 | 2.1 | 10.4 | 15.7 | 25.6 | 4.5 | 9.7 | 4.2 |
| | Old | 2.5 | 2.0 | 8.6 | 16.2 | 2.8 | 2.3 | 12.6 | 21.9 | 23.0 | 4.3 | 7.5 | 4.8 |
| Inferential Statistics | | | | | | | | | | | | | |
| | | F | p | F | p | F | p | F | p | F | p | F | p |
| **Intersection Type (Improved versus Unimproved)** | | 0.01 | 0.97 | 0.41 | 0.52 | 0.11 | 0.74 | 0.55 | 0.46 | 0.67 | 0.42 | 1.60 | 0.21 |
| **Age Group (Older Versus Younger Drivers)** | | 1.16 | 0.29 | 1.04 | 0.31 | 0.36 | 0.55 | 0.10 | 0.75 | 2.84 | 0.10 | 2.68 | 0.11 |
| **Interaction (Age x Intersection)** | | 2.80 | 0.10 | 1.03 | 0.32 | 2.45 | 0.13 | 1.78 | 0.19 | 0.01 | 0.92 | 2.26 | 0.14 |

Tab. 4 - Kinematics data of younger and older drivers during the recovery phase of maneuver 3A & 3B; N = 39 ($n_{young}$ = 19, $n_{old}$ = 20)

| | | RMS Yaw (radians/sec) *10^-2 | | Variance Yaw (radians/second) *10^-4 | | RMS Lateral Acceleration (g) *10^-2 | | Variance Lateral Acceleration (g) *10^-4 | | Average Speed (mph) | | Average Forward Acceleration (g) *10^-2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Descriptive Statistics | | | | | | | | | | | | | |
| **Intersection** | **Age** | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD |
| **Improved** | Young | 2.1 | 2.4 | 8.4 | 22.5 | 2.5 | 3.5 | 18.0 | 54.7 | 32.9 | 33.7 | 8.6 | 3.6 |
| | Old | 1.8 | 0.9 | 2.9 | 3.7 | 1.4 | 1.2 | 3.5 | 5.9 | 21.3 | 5.5 | 4.7 | 3.4 |
| **Unimproved** | Young | 3.3 | 3.3 | 18.6 | 34.1 | 3.1 | 3.5 | 20.0 | 53.4 | 29.4 | 12.6 | 9.3 | 4.4 |
| | Old | 3.3 | 3.1 | 17.4 | 32.2 | 3.3 | 5.0 | 33.5 | 122.7 | 24.6 | 9.4 | 6.6 | 3.5 |
| Inferential Statistics | | | | | | | | | | | | | |
| | | F | p | F | p | F | p | F | p | F | p | F | p |
| **Intersection Type (Improved versus Unimproved)** | | 9.85 | 0.01 * | 6.73 | 0.01 * | 2.13 | 0.15 | 0.91 | 0.35 | 0.01 | 0.97 | 5.77 | 0.02 * |
| **Age Group (Older Versus Younger Drivers)** | | 0.15 | 0.70 | 0.24 | 0.63 | 0.31 | 0.58 | 0.01 | 0.97 | 4.09 | 0.05 * | 9.22 | 0.01 * |
| **Interaction (Age x Intersection)** | | 0.48 | 0.49 | 0.20 | 0.66 | 0.68 | 0.41 | 0.68 | 0.42 | 0.61 | 0.44 | 1.31 | 0.26 |

Tab. 5 - Kinematics data of younger and older drivers during the recovery phase of maneuver 4A & 4B; N = 39 ($n_{young}$ = 19, $n_{old}$ = 20)

| | | RMS Yaw (radians/sec) *10^-2 | | Variance Yaw (radians/second) *10^-4 | | RMS Lateral Acceleration (g) *10^-2 | | Variance Lateral Acceleration (g) *10^-4 | | Average Speed (mph) | | Average Forward Acceleration (g) *10^-2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Descriptive Statistics | | | | | | | | | | | | | |
| **Intersection** | **Age** | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD | Ave | SD |
| **Improved** | Young | 2.8 | 3.3 | 14.0 | 28.6 | 2.2 | 1.9 | 7.4 | 11.8 | 24.6 | 5.0 | 0.09 | 0.04 |
| | Old | 2.5 | 2.0 | 9.0 | 13.5 | 1.9 | 1.3 | 5.0 | 6.2 | 21.4 | 4.6 | 0.19 | 0.59 |
| **Unimproved** | Young | 2.1 | 2.0 | 8.2 | 16.7 | 2.2 | 2.5 | 10.6 | 23.5 | 26.2 | 6.0 | 0.09 | 0.04 |
| | Old | 2.3 | 2.1 | 9.6 | 23.8 | 2.1 | 1.7 | 7.3 | 12.5 | 20.9 | 4.7 | 0.05 | 0.03 |
| Inferential Statistics | | | | | | | | | | | | | |
| | | F | p | F | p | F | p | F | p | F | p | F | p |
| **Intersection Type (Improved versus Unimproved)** | | 0.71 | 0.40 | 0.38 | 0.54 | 0.10 | 0.76 | 0.71 | 0.40 | 0.39 | 0.54 | 1.05 | 0.31 |
| **Age Group (Older Versus Younger Drivers)** | | 0.01 | 0.95 | 0.11 | 0.74 | 0.13 | 0.72 | 0.68 | 0.42 | 10.76 | 0.01 * | 0.18 | 0.67 |
| **Interaction (Age x Intersection)** | | 0.36 | 0.55 | 0.55 | 0.46 | 0.15 | 0.70 | 0.02 | 0.88 | 1.22 | 0.28 | 1.28 | 0.27 |

## 6. Discussion

The present study examined kinematic data derived from the simulator's computer during a simulated drive. Only data generated during the recovery phase are reported in this study. Our working assumptions were that safe driving is contingent on a combination of vehicle stability and driver's confidence and that stability and confidence can be inferred from kinematic measures. We used variability measures (variance and RMS) of yaw and lateral acceleration to demonstrate the vehicle's departure from its expected linear path and thus to denote lateral stability.

Likewise, we used average speed and forward acceleration to indicate driver's confidence [21]. Our notion was that drivers would negotiate the turn of the improved intersection with smaller lateral forces impacting the simulator's car and that therefore the recovery phase will show greater stability.

This greater stability will then allow the driver to travel at a greater speed and lower forward accelerations, illustrating greater driver's confidence. We analyzed the recovery phase from a turn at improved versus unimproved intersections to indicate safe driving of older versus younger drivers. We hypothesized that implementing the proposed FHWA guidelines for highway design to increase older driver safety (the improved intersections) would result in greater lateral stability (as expressed by significantly smaller RMS and variance of yaw and lateral acceleration) during the recovery phase when compared to the unimproved intersections. The findings of the present study supported this hypothesis for only one of the four maneuvers, the left-turn offset (maneuver 3). In two of these four maneuvers, the right-turn channelization (maneuver 2), and the protected left-turn signal phase (maneuver 4), we found no differences in lateral stability during the recovery phase between the improved and unimproved intersections. This is not surprising, as these intersection-pairs were the exact geometric replication of each other, with the same road curvature and turn radius. In addition, the enhance safety features of the improve intersections may have affected the turn phase [18,19] more than the recovery phase. Finally, maneuver 1 (extended receiving lane) revealed the opposite than the hypothesized results, i.e., poorer lateral stability (significantly greater RMS and variance of yaw) for the improved intersection. These results may be explained by the fact that the controls of the driving-wheel of the simulator's car were over-sensitive and required a lot of corrections when returning to a linear path after the turn. Thus, the extended receiving lane, which allowed the drivers to make a larger diameter turn, also caused them to deviate more from the expected linear path during recovery.

We also hypothesized that the recovery phase of the improved intersections would be driven with greater driver's confidence (as expressed by increased average speed) than the unimproved intersections.

However, all four maneuvers did not reveal differences in driver's confidence (speed) between the improved and unimproved intersections. Perhaps average speed was not a sensitive enough measure to reveal difference in the recovery phase. Indeed, when analyzing the time it took to travel through the 500 feet of recovery (beyond the turn), both maneuver 1 and 3 had significant differences between the improved and unimproved intersections.

For the main effect of age group, we hypothesized that older drivers would exhibit poorer lateral stability (significantly greater RMS and variance of yaw and lateral acceleration) during the recovery phase as compared to younger drivers. This was true for maneuver 1, extended receiving lane. The other three maneuvers showed no differences in lateral stability during the recovery phase between older and younger drivers. Epidemiological studies show that younger drivers engage in more risk taking driving behaviors than their older counterparts [28]. Thus, we postulated that compared to the older drivers, the younger drivers would recover at both improved and unimproved intersections with greater speed and forward acceleration. In addition, older drivers generally require longer processing time [29], show decreased reaction time [30], and are more cautious than younger drivers [28]. Thus we expected the older participants to drive the recovery phase with less confidence and more caution, as expressed by lower average speed and forward acceleration than younger drivers. All three left-turn maneuvers behaved as expected. The right-turn (maneuver 2) exhibited no difference in average speed between older and younger drivers. Since we did not have approaching vehicles in these right turns, the drivers did not have to merge into traffic and thus did not need to increase their speeds in order to match that of the approaching vehicle.

The lack of significant interactions in any of the maneuvers suggests that older drivers did not benefit more or less from the implementation of the proposed FHWA guidelines than younger drivers. Had only older drivers benefited from these guideline, we would have found significant interactions showing more improvement in driving performance of older drivers than for younger drivers in the improved intersections.

The most consistent differences in kinematic data were in average speed between age groups. The older drivers exhibited reduced speed, which implied that they were less confident and more cautious than younger drivers during recovery form a left-turn. This difference, however, may not express a true difference in driving safety but rather a level of comfort with technology. Younger adults are much more familiar with video-games and computer technology than older people. Nevertheless, the fact that there were no differences between age groups in average speed during recovery from a right-turn may indicate that our data and assumptions are correct and that older drivers are not as confident as younger drivers when performing left turns.

The limitations of the study are mostly related to its sample. The relatively small sample size is partially due to simulator sickness symptoms, causing an attrition rate of 35% for the older and 17% for the younger participants. Also the gender composition of the two groups is dissimilar, with women composing the majority (68%) of the younger group but only 10% of the older group. Again, simulator sickness symptoms may have caused this incongruence. Thus, selection bias due to simulator sickness is very likely. In addition, the experience of driving the simulator and may be very different than on the road driving. For example, the steering of our simulator car was over-sensitive and required more corrections than driving most real vehicles. Therefore, caution should be used when interpreting the results of this study.

In addition, we were surprised to find significant differences in yaw without corresponding significant differences in lateral acceleration. The only explanation that we could come up with for this conflicting evidence was that the simulator algorithms calculating the yaw and lateral acceleration of the vehicle were not perfectly coordinated. We are in discussion with the simulator company regarding these findings and the calibration of the simulator.

## 7. Conclusions

The kinematics findings of the present study suggested that the FHWA guidelines for implementing safe road conditions may be helpful for both younger and older drivers in one of the four improved intersections (left-turn offset). We found that older drivers did not benefit more or less than younger drivers from implementing the FHWA guidelines. We also found differences between younger and older drivers. Younger drivers travelled at higher speeds through the recovery phase of the three left-turn intersections (both improved and unimproved). The findings of the present study may provide critical information for those involved in the design of roadway systems, such as engineers, planners, and policy makers, to enhance safe driving. These findings, however, need to be interpreted with caution due to potential incongruencies existing between driving the simulator and the actual road course.

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