

Validation of stopping and turning behavior for novice drivers in the National Advanced Driving Simulator

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The leading cause of death for teens in the US is motor vehicle accidents. Per miles driven, teens are more likely to be involved in accidents than other age groups, but research looking at on-road behavior is limited by the dangers involved. Driving simulators provide a safe environment in which to examine the behaviors that may contribute to teen drivers' higher risk of crash involvement. For this study, 21 sixteen-year-old males drove on the road in their own vehicles and over similar routes in the National Advanced Driving Simulator approximately six weeks after obtaining their intermediate licenses. The route included interstate, two-lane rural highway, and residential driving. Data from three intersections where the driver needed to stop and turn were compared. This paper compares the similarities between acceleration and velocity profiles across the 21 participants. The results show that when the simulator intersection closely matched the real-world intersection, novice driver performance was similar in these two environments.

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Introduction

The ability of simulators to replicate actual on-road driving behavior is of significant interest to researchers and training professionals working in the driving simulation field. For simulators to be useful in either training or research, it is necessary that the stimuli provided in the simulated environment elicit the same type of response from drivers in both environments. A common approach is to validate the vehicle models that underlie the operation of the simulator and rely on the face validity of the simulator environment to provide overall validity for the results. However, validity is also believed to be dependent on a specific research question (Kaptein, Theeuwes, and Van Der Horst, 1996).

In order to better understand how novice teen drivers might respond in a virtual simulation environment, the National Advanced Driving Simulator (NADS), in conjunction with the Children's Hospital of Philadelphia (CHoP), and with funding from the National Science Foundation (NSF), has undertaken an effort to validate novice teen driver response in a high-fidelity motion simulator to that in the real world. This validation effort was undertaken as part of a larger overall study that surveyed novice teen drivers and their parents during the first six months of licensure and also examined novice teen driver response to high task loads, such as cell phone use, in a simulated driving environment (Senserrick et al., 2007).

A key issue associated with teen drivers is their ability to judge appropriate gaps (McKenna, Waylen, and Burkes, 1998) and to complete specific maneuvers. One example of this would be a left turn across traffic. In 2004 in North Carolina, drivers between the ages of 16 and 19 accounted for 23.4% of all crashes in which left turns were the first harmful event (University of North Carolina). To better study this issue in a simulated environment, we first need to better understand how teens negotiate left turns in the simulator. This validation study allows for the examination of how well novice teen drivers respond to similar intersections in the simulated and real worlds.

The left turn is widely recognized as one of the most difficult maneuvers to safely execute on U.S. roadways (Noyce, 1998). In fact, in 2005 alone, there were approximately 1,050,000 accidents by vehicles turning left (NHTSA, 2005). Left turning maneuvers account for 10.9% of all accidents, the second highest of all maneuvers (NHTSA, 2005). As such, it is important to be able to safely and accurately research these maneuvers, which may be accomplished using simulation.

Numerous simulation studies have investigated left turns. These studies most commonly focus on gap acceptance and evaluation of protected/permitted left turns (PPLT). Turns are generally avoided when they are not the focus of research due to the difficulty in accurately portraying motion cues to the driver. Motion mismatch is called many things—for example, sensory conflict theory, cue conflict theory, neural mismatch theory—and is often the cause of simulator sickness (Johnson, 2005). This motion mismatch often causes drivers to alter their behaviors to minimize the effect of perceived mismatches. This alteration of their typical driving results in behaviors that is often not typical of real-world driving. Of the seven simulator studies presented in the *Journal of the Human Factors and Ergonomics Society* in 2005 and 2006, only two included scenarios with turns (Pradhan et al., 2005; Pollatsek et al., 2006).

Methods

Participants

Male participants from the larger survey study who received their intermediate licenses between April and October 2006 were invited to participate in the simulator portion of the study. Due to their age, informed consent forms were sent to them and their parents prior to the scheduled simulator visit.

Participants drove two simulator drives and one on-the-road drive during a single visit to the NADS during their second month of licensure. Half of the participants completed the on-the-road drive first, and half completed the simulator drives first. A data logger was installed in each participant's own vehicle prior to the on-the-road drive and was removed after that portion of the visit was completed. Participants were asked to drive normally and safely on both the public roads and in the driving simulator.

Simulator and Driving Apparatus

NADS-1 provides a high degree of fidelity, to the extent that the environment produced by the simulator matches the environment being simulated (Farmer, et al., 1999), through features such as a 360-degree field of view, vehicle-specific dynamics models combined with a 13-degree-of-freedom motion system, interactive traffic, and actual vehicle cabs. The NADS-1 records a variety of data, such as position, acceleration, velocity, and steering angle. These measures are recorded at a rate of 60 Hz. The simulator to on-the-road validation protocol was leveraged from a previous (unpublished) National Highway Traffic Safety Administration (NHTSA) project that validated the simulator for older driver research.

On-the-road driving data were collected by means of a simple data logger, which was installed in each participant's own vehicle. The device was unobtrusive and was connected to the on-board diagnostic (OBD) port under the dashboard of the vehicle. This is the same port that mechanics use to perform diagnostic checks on vehicles and commercial devices (e.g., CarChipE/X, Davis Instruments, San Diego), and posed no additional risk to participants or their vehicles. Due to limitations in the reliability and sampling frequency of the commercially available devices at the time of this study, the logging device was constructed by NADS engineering personnel and comprised a micro-processor, an accelerometer, and a global positioning system (GPS). The data logger recorded data at a rate of 2 Hz.

On-the-road and Simulator Drives

The on-the-road route began at the NADS facility and proceeded north following a route that included suburban, rural highway, and interstate driving environments. Participants returned to the NADS facility along a different route that included the same types of driving environments. The length of the route was approximately 42 miles. The simulator drives replicated the on-the-road route as much as possible by using GPS data as the basis for constructing the simulated environment. The simulated environment contained no traffic impeding the driver so that free (unconstrained) speeds could be recorded; however, traffic was present and uncontrolled during the on-the-road drives, which could have impacted recording free speeds. Several different aspects of speed and acceleration were examined for each segment driven.

The first intersection is a controlled intersection, a 4-way stop. Figure 1 below shows an

aerial image of the intersection in the real world with black and blue lines representing the virtual world laid on top of it. The blue line represents the edge of the road as it would appear in the simulator. The virtual representation of the intersection is fairly close to the real-world intersection.

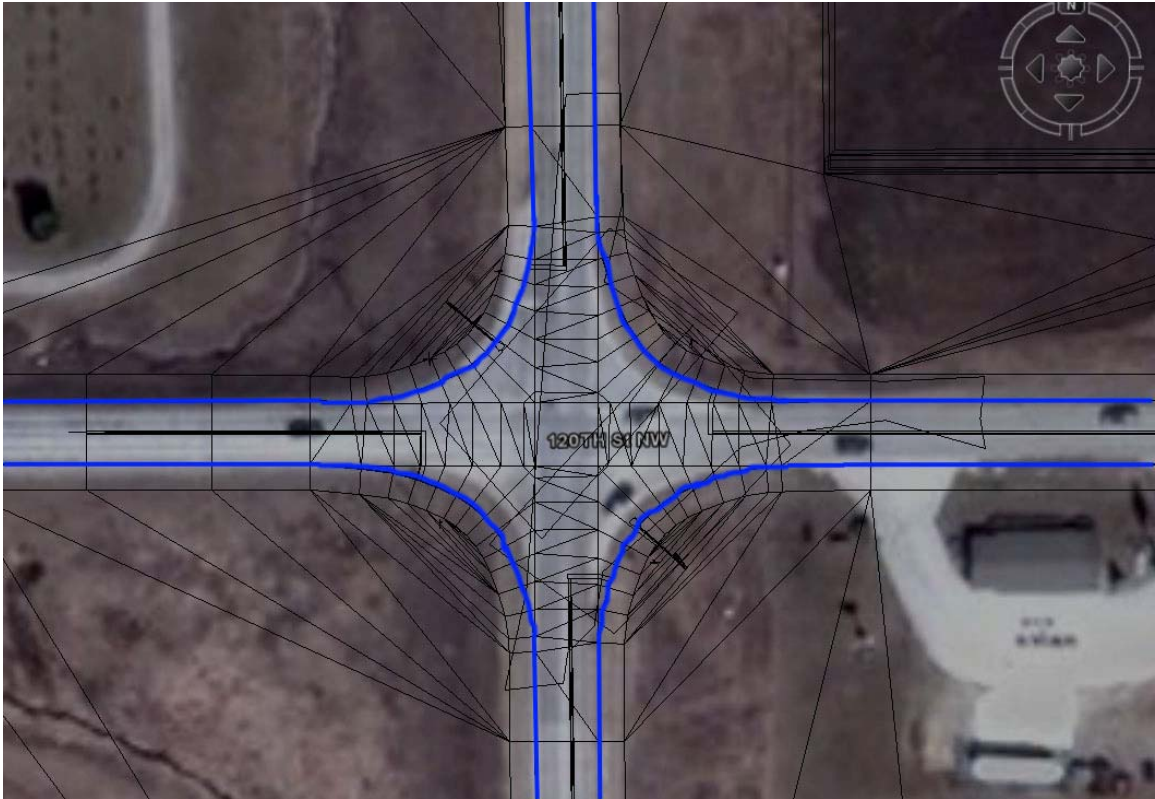


Figure 1: 4-way stop, virtual (blue) overlaid on real world.

Figure 2 below shows an aerial image of the second intersection. This intersection has a turn lane and is uncontrolled with respect to the path the participants drove. The blue lines represent the edge of the virtual road seen in the simulator. The virtual representation of the intersection is relatively close to that of the real world. The virtual world was created prior to construction that created the west-bound street.

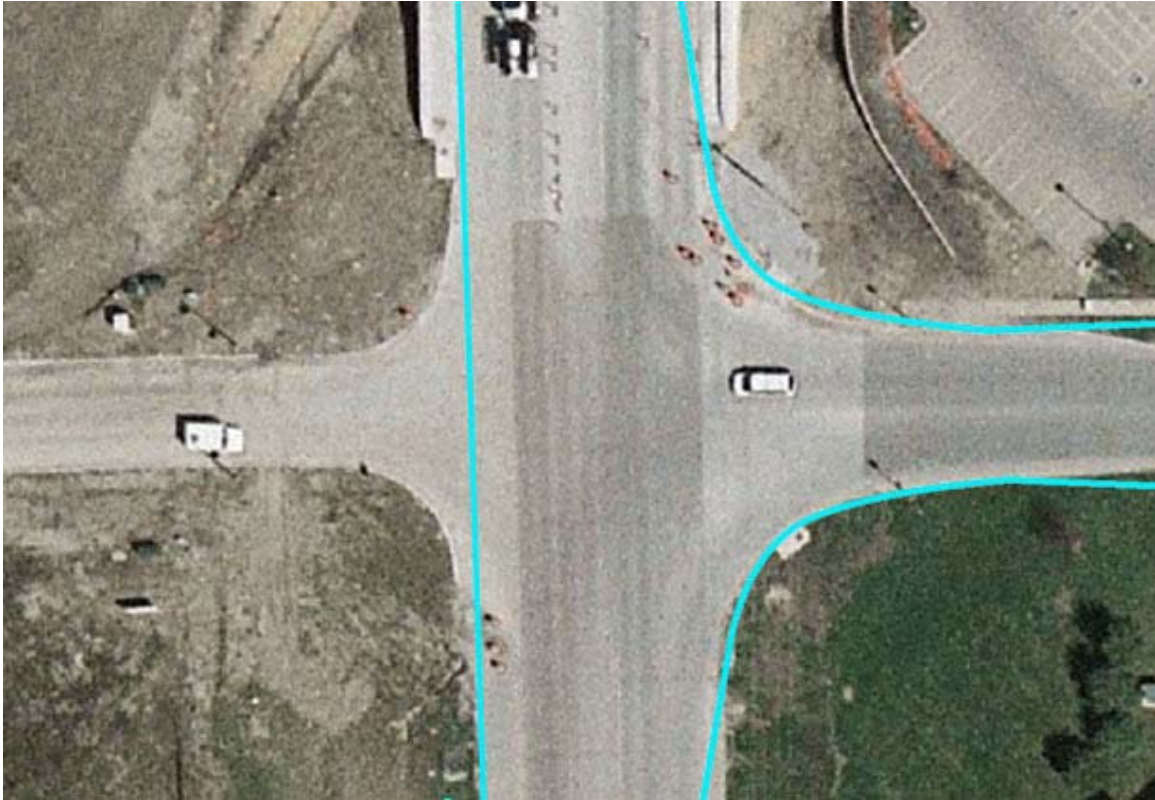


Figure 2: Uncontrolled intersection with turn lane, virtual (blue) overlaid on real world.

The final intersection analyzed, a T-intersection, is shown in Figure 3. The edge of the road as seen in the simulator is again highlighted in blue. The virtual representation of this road does not closely match that of the real world. As can be seen in the figure below, the intersection has a much smaller radius turn in the real world. This difference in turning radius meant that the angle turned in the real world was greater than in the virtual world by about five degrees.



Figure 3: T-intersection, virtual (blue) overlaid on real world.

Procedure

The simulator and on-the-road trials involved two drives in NADS-1 and one on-the-road drive in the teen's personal vehicle. Eleven of the 21 participants completed the on-the-road trial first, and ten completed the simulator drives first. Participants drove for approximately one hour in the NADS-1 and for 40 minutes on public roads.

Prior to the on-the-road drive, participants were shown the on-the-road route they would drive and were allowed to ask questions. An experimenter escorted the participants to their vehicles, provided route instructions during the drives, and escorted participants back into the NADS facility. Participants were asked to drive normally and safely on public roads and in the NADS. Participants were given a break and were offered a beverage and a snack between the on-the-road and simulator portions of their visit.

All participants completed the five simulator drives in the same order divided into two sessions. The first session included the rural drives, which were over similar types of roads and through driving situations similar to those encountered during the on-the-road drive. Following their break, participants were allowed to review the route map again. Participants were then introduced to the experimenter who would ride with them during their simulator drives. Participants were escorted to the simulator, given an orientation to the vehicle cab in the simulator, and given general instruction about their drives in the simulator. Participants completed the two rural drives and were then escorted back to a participant room. The remaining three simulator drives examined novice teen driver response to high task loads, such as cell phone use, in a simulated driving environment, which was not duplicated in the on-the-road drive and will not be discussed here.

Independent Variables and Dependent Measures

The independent variable in each of these analyses is environment, which is at two levels: simulator and on-the-road. Environment is a within-subject variable. The seven dependent measures are minimum speed, mean speed, end speed, minimum and maximum longitudinal acceleration, and minimum and maximum lateral acceleration.

Results

Three left turn segments were analyzed. As the intersections vary in size, each analysis is slightly different. Each of the intersections was analyzed from 36.5 meters on either side of the intersection of the two roads' centerlines. This distance encased each of the intersections, the stop signs if they were present, and a short distance used to slow/stop. On-the-road data, collected at a frequency of 2 Hz, was compared with simulator data, which was down-sampled from 60 Hz to 2 Hz.

The results for the dependent measures for the three intersections are shown in Table 1. The statistically insignificant results are of interest because they show where the measures did not differ between the two environments (simulator and on-the-road). The magnitudes of the differences between the two environments are also of interest and are shown in Table 1. Positive differences indicate lower speed or acceleration on the road than in the simulator. Statistically *insignificant* differences are shown bold and in italics.

Table 1: Results for dependent measures.

<u>Dependent Measure</u>	<u>4-way Stop</u>		<u>Uncontrolled</u>		<u>T-Intersection</u>	
	Significance	Difference	Significance	Difference	Significance	Difference
Min. Speed (m/s)	F= 5.52 p= 0.0304	-0.816	F= 8.20 p= 0.0133	2.273	F= 0.97 p= 0.3388	0.216
Mean Speed (m/s)	F= 0.48 p= 0.4961	0.304	F= 11.49 p= 0.0048	2.277	F= 22.11 p= 0.0002	1.627
End Speed (m/s)	F= 12.65 p= 0.0023	0.752	F= 116.80 p< 0.0001	2.634	F= 130.88 p< 0.0001	2.714
Min. Long. Acceleration (m/s²)	F= 0.07 p= 0.7981	0.062	F= 3.86 p= 0.0712	-0.558	F= 0.34 p= 0.5677	-0.087
Max. Long. Acceleration (m/s²)	F= 10.67 p= 0.0043	0.414	F= 15.43 p= 0.0017	-0.591	F= 11.98 p= 0.0028	0.491
Min. Lat. Acceleration (m/s²)	F= 15.62 p= 0.0009	0.793	F= 0.00 p= 0.9868	-0.004	F= 17.08 p= 0.0006	0.759
Max. Lat. Acceleration (m/s²)	F= 3.85 p= 0.0654	-0.229	F= 0.05 p= 0.8193	0.025	F= 3.23 p= 0.0892	0.129

Two acceleration measures, minimum longitudinal acceleration and maximum lateral acceleration, had insignificant differences between the on-the-road and simulator data at all three intersections. Two acceleration measures were found to have significant differences: maximum longitudinal acceleration and minimum lateral acceleration. The controlled intersections, 4-way stop and T-intersection, show higher maximum longitudinal accelerations in the simulator than on the road. However, the uncontrolled

intersection shows the opposite. This difference is likely due to interaction with oncoming traffic. Drivers are likely to accelerate more to fit between gaps in the oncoming traffic, a situation that is not present in the simulator. Interaction with oncoming traffic may have also influenced the magnitude of the differences in several of the dependent measures, producing more significant effects than if the same level of oncoming traffic had been present in both environments.

The differences in minimum lateral acceleration are similar to that of maximum longitudinal acceleration, with higher accelerations in the simulator at the 4-way stop and the T-intersection than on the road. However, the uncontrolled intersection shows an insignificant difference between the simulator and on-the-road data. The minimum lateral accelerations in the uncontrolled intersection are again very similar on the road and in the simulator.

The controlled intersections show some differences that are unlike the differences discussed above. At the 4-way stop, participants had higher lateral accelerations on the road than in the simulator. At the T-intersection, the opposite occurred. One possible explanation is the different type of intersection; another possible factor is the difference between the real-world T-intersection and the simulated T-intersection. In the simulator, this is a much larger and wider turn than the sharp turn that exists in the real world, as shown above in Figure 3. Therefore, participants would have to take the turn slower in the real world, resulting in smaller maximum lateral accelerations.

Numerous velocity variables were analyzed as well. The analysis of the intersections was over the same area; however, the intersections varied in size, shape, and traffic control devices (uncontrolled, stop sign, traffic lights). Minimum speeds through the intersections illustrate some interesting points. Both the 4-way stop and the T-intersection have stop signs, but at the 4-way stop, only four (19%) of the participants actually came to a complete stop in both the simulator and the real world. On average, participants only slowed down to 1.0 m/s in the simulator, and nearly twice that, 1.8 m/s, on the road. Participants did not slow down nearly as much at the uncontrolled intersection in the simulator as they did in the real world, again likely due to the interaction with traffic in the uncontrolled intersection. The T-intersection showed no significant difference between the simulator and the real world.

Mean speed was not significantly different on the road than in the simulator for the 4-way stop; this was the intersection for which the dimensions most closely match in the simulator and on the road. The differences in mean speed at the uncontrolled intersection and T-intersection could have been influenced both by interaction with traffic and by the difference in intersection dimensions.

End speed, the last speed value recorded while in the pre-defined intersection, was significantly different in each of the intersections. Again, the 4-way stop shows little difference between the simulator and the real world. The uncontrolled intersection shows a greater difference, which was expected. Without interaction with traffic in the simulator, participants are able to enter and take the turn at higher speeds, therefore exiting the turns at higher speeds and taking less time to return to speed. The T-intersection again shows a large difference, which is likely due to the physical differences between the virtual and real worlds.

Discussion

Due to budget and schedule constraints, the decision was made to implement the virtual environment by leveraging existing assets instead of conducting extensive surveys of all intersections driven along the routes. An attempt was made to ensure similarities between the actual, real-world intersections and their virtual representations, while acknowledging the resulting loss of realism this approach engendered. Additional differences were introduced by avoiding the use of small radius turns for the virtual environment, limiting severe turns to 15 meters, which in the real-world might be as small as 8.5 meters. These decisions are similar to those inherent in all research studies. Careful consideration of what is needed to answer the experimental questions informs decisions in the design stage of studies. In turn, such decisions must be taken into account when generalizing from results of research studies.

While there were numerous significant differences between the driving behaviors shown on the road in the simulator, some trends were also revealed. When the virtual intersections represented real-world intersection geometries accurately, as in the 4-way stop and uncontrolled intersections with turn lanes, accelerations in both environments matched closely. The bigger the differences between the simulator and the real-world intersections, the larger the difference in behaviors can be.

Another possible cause of behavioral differences is interaction with traffic when intersections are not controlled. When drivers are forced to slow for other vehicles, or to fit between gaps, their behaviors can change drastically. This difference may be accounted for in the simulator with representative, randomized interactions with traffic.

When virtual environments represent the real-world locations more accurately, and when traffic is introduced, it may be possible to simulate drives in such a way that real-world turning behaviors are replicated with greater fidelity within the simulator.

References

- Farmer, E., van Rooij, J., Riemersma, J., Joma, P., & Morall, J. (1999). *Handbook of Simulator Based Training*. Aldershot, Hampshire, UK: Ashgate.
- Johnson (2005). *Research Report 1832: Introduction to and Review of Simulator Sickness*. U.S. Army Research Institute for the Behavioral and Social Sciences, Arlington, VA.
- Kaptein, N.A., Theeuwes, J., & Van Der Horst, R. (1996). Driving simulator validity: Some considerations. *Transportation Research Record 1550*.
- McKenna, A.P., Waylen, A.E., & Burkes, M.E. (1998). *Male and Female Drivers: How Different Are They?* Berkshire, UK: University of Reading, Foundation for Road Safety Research.
- NHTSA (2005). *DOT HS 810 630: Traffic Safety Facts 2005*. Washington, D.C.: Author.
-

Noyce, D.A. (1998). *Development of a Uniform Traffic Signal Display for Protected/Permitted Left Turn Signal Displays*. Ph.D. Dissertation, Texas A&M University, College Station, TX.

Pollatsek, A., Narayanaan, V., Pradhan, A., & Fisher, D.L. (2006). Using eye movements to evaluate a PC-based risk awareness and perception training program on a driving simulator. *Human Factors*, 48 (3), p. 447-464.

Pradhan, A.K., Hammel, K.R., DeRamus, R., Pollatsek, A., Noyce, D.A., & Fisher, D.L. (2005). Using eye movements to evaluate effects of driver age on risk perception in a driving simulator. *Human Factors*, 47 (4), p. 840-852.

Senserrick, T., Brown, T., Marshall, D., Quistberg, A., Dow, B., & Winston, F. (2007). *Risky Driving by Recently Licensed Teens: Self-Reports and Simulated Performance*. Paper presented at the Driving Assessment Conference, Stevenson, Washington.

University of North Carolina: Highway Safety Research Center. *North Carolina Crash Data*. Retrieved June 11, 2007, from <http://www.hsrb.unc.edu/crash/>.
