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ABSTRACT: Novice drivers are more likely to be involved in vehicle crashes than more experienced drivers. Transportation system simulators, such as aerospace, automotive, and rail, have been used effectively over several decades in support of operator training and research studies. The immersive high-end automotive simulators tend to be large-scale, difficult to move, and relatively cost ineffective for widespread deployment. In contrast, a mobile vehicle training system often features simplistic environments which are not readily accepted by teenagers who evaluate the driving experience as compared to commercial video games. Consequently, a need exists for a low-cost portable automotive training system that provides a higher level of realism with superior graphics for novice drivers. In this paper, a turn-key computer system is presented with performance evaluations to assist novice drivers in the improvement of their driving skills. The custom simulator was assessed by 50 participants who answered pre- and post-test questionnaires and drove the simulated vehicle around a preset course. The participants overall simulated driving score improved 28% with gains in both driving knowledge (questionnaire) and proficiency (test track). The simulator presented to participants and described by this paper prove to be effective at raising both driving knowledge and skills. The simulator described in this paper represent an important resource for driver training programs. The next test of its effectiveness will be its integration into a nationwide safe driving program to complement in-vehicle instruction with simulator based virtual instruction.

Keywords: Driver education, automotive simulators, assessment, training, driving skills

1. INTRODUCTION

Young drivers, particularly those between the ages of 16 and 23, have more than double the number of car crashes than older drivers (McCartt, Mayhew, Braitman, Ferguson, & Simpson, 2009). Researchers have identified several factors that may cause novice drivers to have more crashes than experienced drivers. First, young drivers have less experience operating vehicles on the roadways and usually overestimate their driving skills (Craen, Twisk, Hagenzieker, Elffers, & Brookhuis, 2011). Second, most young drivers are not as familiar with traffic laws since their past experiences were largely derived as passengers (Dols, Pardo, Verwey, & Ward, 2001). Third, novice drivers may inaccurately gauge the speed of cars around them and/or the relative distance between surrounding vehicles (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; Scialfa et al., 2011). Unfortunately, this inexperience may cause them to suddenly decelerate their vehicles and/or change lanes without noticing approaching cars. Finally, young drivers may be more easily distracted by various factors such as roadside advertisements, electronic devices including MP3 players, cell phones, and portable video games, which draw their attention away from the roadway (Green, 2010). Therefore, driver education programs should help novice drivers understand the danger of inexperience and gain critical knowledge and skills through focused classroom, in-vehicle, and simulated instruction.

Driver education and training laws and programs have existed for many years. The Graduated Driving License (GDL) Program, first introduced in 1996 in Florida, has been adopted throughout the United States in various forms. The GDL attempts to increase young driver safety while decreasing their crash rates through restricted motor vehicle operation. Young drivers need to pass the standard written and in-vehicle driving tests for licensure. The written test requires drivers to answer basic questions designed to evaluate their knowledge of proper vehicle operation, while the vehicle driving test assesses the driver's mastery

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of fundamental driving skills (Ferguson, 2003). The GDL imposes age-based restrictions on motor vehicle operation. For example, the driver may only operate their vehicle at certain times and without passengers below a prescribed age. As the young driver matures, these restrictions are decreased until the individual is fully licensed. Although the GDL program generally has been successful, a number of limitations exist including: (1) GDL typically calls for parents to supervise young drivers practice driving; so teaching effectiveness and practice session hours depend on the parents' skills, time, and interest (Jacobsohn, Garcia-Espana, Durbin, Erkoboni, & Winston, 2012); and (2) the driving proficiency test commonly occurs during daytime hours on local roads with minimal traffic, so the driver's proficiency is not fully evaluated on all roads or during nighttime. Consequently, the need to better train novice drivers continues.

Simulations have long been used as an effective training method. For example, the Armed Forces use simulation to train their members about judgment and marksmanship. Pilots use simulators prior to flying airplanes, helicopters, and advanced fighter jets. Emergency vehicle drivers use simulators to learn safe driving maneuvers. The use of a simulator eliminates the possibility of the learner endangering themselves, others, or equipment. Nearly 50 years ago, it was demonstrated that novice driver knowledge and skill test scores were effectively the same when educational programs using driving simulators along with on-road instruction were compared with programs that used on-road instruction alone. R.O. Nolan (1965) found comparable results in driver attitude, knowledge, and skill between one group of students who were trained using a classroom simulator and on-street instruction and another group who were taught on a multiple car off-street driving range and on-street instruction. R.E. Gustafson (1965) studied the differences in driver attitude, knowledge, and skill between one group of students who were trained exclusively on a multiple car off-street driving range and another group who were taught using an Allstate Good Driver Trainer and on a multiple car off-street driving range. While the first group scored higher on vehicle handling, no significant differences were found in attitude, knowledge, or general driving ability related to handling traffic and road problems.

In 2008, Flach, Dekker, and Stappers reported that making mistakes on a driving simulator is an important way for drivers of varying degrees of experience to learn more. In a 2010 AAA Foundation for Traffic Safety study, Lonero and Mayhew reported simulators and other technology advances were sensible teaching tools for driver education programs but do not replace supervised on-road experience. Perna (2010) found a fixed base driving simulator to be an effective learning tool for both students preparing to obtain a driver permit as well as for novice drivers. She worked with students with autism spectrum disorder and cognitive disabilities and reported learning and the perception of learning was hindered only by mechanical glitches. In 2011, Ball found an on-line virtual world environment was a viable option for providing general driving training to young drivers. He found students who spent 13-18 minutes in the environment earned driving knowledge test scores within two points of students who participated in a six-hour safe driver program that included 2-hours of classroom training.

Racing games are a type of a virtual driving simulator which has flourished over the past two decades. Some video games, such as the Sony Computer Entertainment's (2012)"Grand Turismo 5" and Electronic Arts' (2012) "Need For Speed", are quite adept at mimicking real world conditions and pose the question of whether it would be possible to educate novice drivers using immersive automotive simulators. Young drivers are more likely to spend time practicing a driving skill if it is also delivered in an entertaining manner (Wahlberg, 2010). Furthermore, a greater variety of driving scenarios can be created within a simulation environment much easier than they can be implemented at a test track. The scenarios implemented in a simulator are also inherently safer than their real world equivalents and allow risky scenarios such as two wheels off, excessive speeding, driving too close to a lead vehicle, using a mobile phone while driving (including text messaging), and violating traffic rules. Based on this concept, driving simulators designed specifically for training young drivers have been developed (Kemeny & Panerai, 2009).

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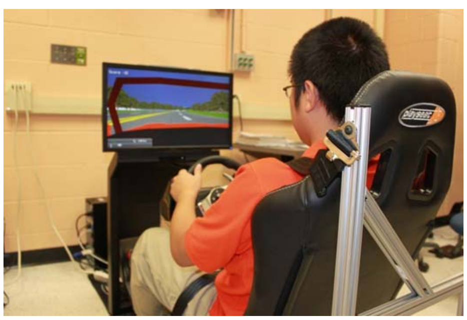
Through the efforts of the researchers, virtual driving simulators to train young drivers have become more effective and practical (Park Lim, 2011).

Norfleet, Wagner, Alexander, and Pidgeon (2009) applied a large scale virtual driving simulator to improve driving skills. However, since the simulator was fixed in a psychology laboratory, it was not practical for training people off the Clemson University campus. Thus, it became apparent that a more portable version of the driving simulator would be ideal. The Clemson Automotive Training System (CATS), a portable driving simulator (shown in Figure 1), has been developed to help improve driving experiences and reduce



potentially dangerous behaviors (Yao, Wagner, Alexander, Pidgeon, 2013).

Figure 1: Portable Clemson Automotive Training System (CATS) with seat belt, standard human / vehicle interface, screen display, speaker, and the host PC workstation

The remainder of this paper is organized as follows: Section 2 introduces the Clemson Automotive Training System, including the hardware, software, features, and track scenarios. Section 3 describes case study. Section 4 presents the results. Section 5 includes the discussion and conclusion. Along with the Nomenclature List appended to this paper, three appendices including the scoring metrics (Appendix A), driving scores and rating (Appendix B), and detailed simulator results (Appendix C) are also included.

2. CLEMSON AUTOMOTIVE TRAINING SYSTEM

The Clemson Automotive Training System (CATS) was assembled using a desktop computer with a 1GB graphic card, a 19 inch monitor with a sound bar, a racing chair that can be adjusted vertically and horizontally, and a Logitech G27 steering wheel with 900 degrees of rotation (refer to Figure 2). The program was coded using C++ and Python, and it was executed in Ubuntu 10.04 (a Linux operating system). The driving track in this simulator highly customized; the track was designed and created using Bob's Track Builder (n.d.) and Blender (Roosendaal, n.d.). The simulator was developed based on VDrift (Venzon, n.d.). The created user interface allows the driver to read information and view images on the screen during driving sessions. One item always displayed on the top left of the screen the participants' driving score that allow them to receive immediate feedback about their driving performance. In addition, a detailed scoring system rate the user's driving skills and viewed during and/or after a run to offer in depth feedback. For example, the average velocity, maximum steering angle, and other information collected and used to analyze the drivers' performances. Finally, several scenarios to evaluate the driver's proficiency were created.

The driving simulator trains young drivers and simultaneously evaluates their driving skills based on four module scenarios. In the

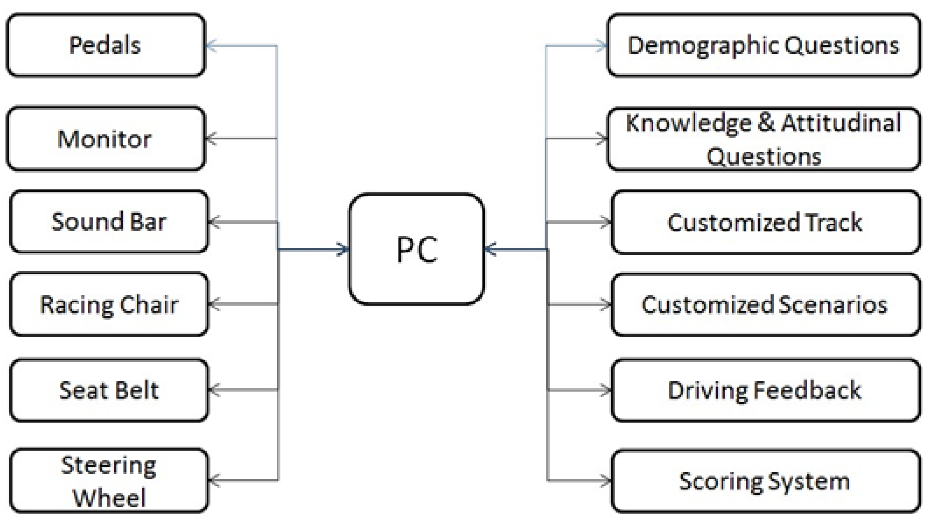


Figure 2. Hardware and software configuration in CATS

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first module scenario - traffic control device - a stop sign located at an intersection assesses whether the driver will stop their vehicle as directed. The next module scenario - lane selection - simulates a blocked lane that tests whether the driver will react appropriately by slowing down and using another lane to avoid the obstacle. In the third - panic braking - the driver must accelerate their vehicle to a high speed and then stop quickly. This scenario is intended to give the driver a sense of their vehicle's limitations, including the vehicle's stopping time and distance, as well as the driver's reaction time during an emergency situation. The fourth module scenario - obstacle avoidance - simulates an animal jumping onto the road and tests how the drivers will react to the event. After the simulation, the drivers view their score for each scenario, allowing them to recognize the areas in which they can improve.

3. METHODS

Introduction to Virtual Driving - Case Study: A human-subjects experiment was designed to test the effectiveness of the virtual driving education simulator to train novice drivers. The case study included a pre-test questionnaire, completion of four driver scenarios on CATS, and a post-test questionnaire. The drivers completed a demographic survey and a pre-test prior to driving. Then, they drove on a virtual test track, in which four modules evaluated different aspects of the drivers' behaviors and reactions to various scenarios. An assessment system recorded different types of data in the background to identify and analyze the drivers' performances. Finally, the driver completed a post-test after completing the modules. The scores from the pre- and post-tests were recorded and compared. The scores of the first and the second simulator driving runs were combined to create a total score.

The steps each participating driver completed were: (a) read the human subjects policy, sign a consent form, and complete a written questionnaire capturing demographic, driving knowledge and habits; (b) sit in the racing chair, buckle the seat belt, and read the instructions to familiarize themselves with the equipment; (c) drive for five minutes on a practice track to learn the CATS throttle, brake, and steering wheel settings; (d) drive on the track for one lap without directions (although, they were able to see the final score after completing this lap); (e) watch a short video indicating the correct method for driving and passing each scenario correctly; (f) drive on the same track for a second time; (g) review the Excel file showing their detailed driving information and their performances and (h) retake the driving knowledge and habits portion of the written questionnaire.

Demographic Survey: Participants completed a brief questionnaire to obtain data about their gender, age, and years of driving experience. They also self-rated their driving ability on a 5-point scale as excellent, good, average, fair, or poor.

Pre- and Post-tests: Participant knowledge was assessed before and after the simulator practices through pre- and post-tests. The final ten question questionnaire was not formally tested for validity and reliability. The test development process utilized Clemson University faculty and staff from education, engineering, psychology, and public health. This panel focused on content and was responsible for developing test items. Learning objectives from the simulator scenarios and general knowledge questions about driving behaviors were used to identify content domains. A pilot study was conducted with 12 college students to confirm content validity. The readability was measured by the Fry formula, and the reading level for test items was at the 5th grade level. The case study participants completed the pre-test prior to any instruction and the post-test following the completion of their time using the CATS simulator. To ensure standardized administration, the same graduate student delivered all tests and CATS simulator instructions using a written script.

Five statements evaluated the subjects' driving behavioral intentions to detect potentially risky driving habits and used a 4-point Likert scale. Five additional multiple choice questions evaluated the subjects' knowledge of proper driving techniques, traffic signs, and safe driving practices. The five behavioral intention statements had a preferred answer choice and the topics addressed were: (1) whether the participants report they are likely to show off their driving skills, (2) the percentage of participants that tend

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to drive over the speed limit,(3) whether wearing a seatbelt makes the participant feel safe, (4) whether the participants would be willing to ride in a car with a potentially unsafe driver if they had no other way home, and (5) whether they felt they were still learning how to be a good driver. The five multiple choice questions were designed to ascertain the subjects' driving knowledge in terms of proper driving techniques, traffic signs, and safe driving practices.

The Driving Score and Driver Rating: Each participant drove through the four module scenarios - traffic control device, lane selection, panic braking, and obstacle avoidance - on the CATS

$$S_i = \begin{cases} \sum_{j=7}^{3} \alpha_{ij} \overline{K}_{ij}; & for(i=1,2,4) \\ \sum_{j=1}^{7} \alpha_{ij} \overline{K}_{ij}; & for(i=3) \end{cases}$$

simulator two times in this case study. An algorithm was created to assess the driver's performance by calculating the driving score (DS) and the driving rating (DR), after they completed the CATS simulator program. The score of each module, Si for (i = 1, 2, 3, 4) corresponds to each driving feature and is expanded as the following equation 1

where i represents the scenario, j represents the items that calculate scores in each scenario, and $\overline{K_{ij}}$ is the metric score, αij is a weight

$$DS = \frac{1}{n}\left(\sum_{i=1}^{4} S_i - \sum_{\kappa=1}^{3} \beta_\kappa N_\kappa\right)$$

indicating the importance of items in each scenario. The values for αij $\overline{K_{ij}}$ have been defined in Appendix A and Yao et al. (2013) provides a more thorough explanation. The overall driving score, which reflects the individual driving score on each module as well as difficulties with speeding, driving off the road, and driving across the double yellow line, maybe calculated as equation 2 where n=4 is used to normalize the final score between 0 and 100, k represents the number of N factors, and β={20, 20, 20}T is a weight

$$DR = \begin{cases} \text{Excellent;} & \text{if } 90 \leq DS \leq 100 \\ \text{Good;} & \text{if } 80 \leq DS < 90 \\ \text{Average;} & \text{if } 70 \leq DS < 80 \\ \text{Fair;} & \text{if } 60 \leq DS < 70 \\ \text{Dangerous;} & \text{if } DS < 60 \end{cases}$$

indicating the importance of each Nk. The difference value comes as a result of a comparison of the first lap and second lap. If the difference value is positive, then the subject improved on their driving skills with the driving simulation.

The driving rating, DR, is based on the driving score, DS, to show a subject's driving performance using the following mapping (refer to equation 3)

4. RESULTS

Demographics: A convenience sample of 50 international college students was recruited for this case study. The case study included 35 males and 15 females and their ages ranged between 23 and 31 years old. Their initial driving classification was based on their years of driving experience; 20 were classified as novice (0-2 years), 21 were classified as beginner (3-5 years), and 9 were classified as experienced (6 or more years). The self-rating results are presented with the CATS-generated driver rating results later in this paper.

Driving Behavioral Intentions: Table 1 exhibits the pre- and post-test responses to the five behavioral intention statements where SD, D, A, and SA correspond to strongly disagree, disagree, agree, and strongly agree, respectively with the asterisked percentage being the preferred safer choice. A positive improvement was noted for four of the five statements. More than 80% of test subjects selected disagree or strongly disagree, indicating they reported being unlikely to show off while driving. A modest decline was noted on their intentions to speed if they felt they had good driving skills. More than 90% of the subjects reported on both tests they felt safer wearing a seat belt although those who strongly agreed with the statement declined on the post-test. Approximately 30% of subjects indicated they would in fact ride with an unsafe or reckless driver if they had no alternative way to go home.

Driving Knowledge: The five questions (and correct answer choice) along with pre- and post-test results are listed in Table 2. The column labeled as "Improvement" shows the percentage of subjects who corrected their answer on the post-test. The first multiple choice

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Table 1. Response to Behavioral Intention Statements Pre and Post-test

Behavioral intention	Pre-Test (%)				Post-Test (%)				% Point Improvement
	SA	A	D	SD	SA	A	D	SD	
I love to show off when I'm driving	4	16	50	30*	6	10	38	46*	16
If you have good skills, speeding is OK	8	36	34	22*	12	24	34	30*	8
Wearing a seatbelt makes me feel safe	68*	28	4	0	62*	30	2	6	-6
I'm still learning to be a good driver	34*	44	18	4	40*	44	16	0	6
I would get into the car with a reckless driver if I had no other way to get home	6	28	36	30*	6	24	30	40*	10

Key for Scale (SA: Strongly agree, A: Agree, D: Disagree, SD: Strongly disagree)

Table 2. Driving Knowledge Questions

Question	Pre-Test (%) Correct	Post-Test (%) Correct	% Point Improvement
What is the proper way a seat belt should be worn?	72	92	20
When driving, you should consistently check the following.	94	96	2
Coming to a flashing red light, what should you do?	74	90	16
While driving on a highway, when do you use your turn signal?	90	96	6
When approaching an intersection with a yellow signal light, it is best to…	66	82	16

question evaluates whether participants knew the correct placement of a lap and shoulder belt. The results show that 72% answered correctly on a pre-test and 92% on a post-test; an overall improvement of 27.77%. The next question addresses whether the subjects knew how to scan for potential hazards while driving and 95% answered correctly. The third question queries the drivers' behavior upon encountering a flashing red light at an intersection; 74% got the correct answer on the pre-test and 90% of the subjects answered correctly on the post-test. The next question asks when a driver should use a turn signal on the expressway. Over 90% of the subjects answered correctly on both the pre- and post-tests. The final question evaluates whether the subjects know the correct response to a flashing yellow light at an intersection, specifically when turning right; 66% of the subjects

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answered correctly on the pre-test and 82% on the post-test.

Driving Performance Using CATS: The drivers' performances on the CATS simulator were evaluated after they finished two laps on each of the four module scenarios. The average driving score for all participants on the first lap was DS = 57. After subjects became familiar with the road and driving scenarios, the average driving score increased on the second lap to DS = 75. This corresponds to an average driver improvement of 31.58%. The driving scores of 11 subjects reflected a lower second run driving scores than their first run. Three drivers achieved the same scores between the first run and the second run. Lastly, 36 subjects improved their driving scores by 3% to 84.5%. The average improvement of the 50 subjects was 28%. The results for each driver are shown in Appendix B.

Testing Scores and Other Factors by Classification: Five factors, including peak velocity, Vpeak, average velocity, Vave, peak steering angle, δpeak, and average steering angle, δave, were found to influence individual subjects' driving performance as shown in Appendix C. Higher testing scores correlated with lower maximum velocities.. Compared to the first run, the second run's Vpeak decreased by 3% while Vave increased by 6%, and the DS increased by 28%. Vpeak decrease suggests that driving improved as the speed decreased. Vave increase shows that driving improved as individual drivers became familiar with the track. Moreover, two factors: the maximum steering angle, δpeak and the δave share the similar trend with the velocity. The lower these three factors, the higher the driving score. In addition, between the first and second run, both factors decreased, with δpeak decreasing the most with a drop of 40%. Steering angle represents the driver's ability to drive the vehicle smoothly; the smaller the steering angle, the better one can control the vehicle. The decreased number of crossing double yellow lines, N1, driving off roads, N2 and driving over the speed limit, N3 indicates that drivers had better control of their vehicles at lower speeds on the second run.

Driver Self-rating and Driver Test-rating: The self rating by participants of their driving skills as well as the rating based on their CATS driving scores are presented in Table 3. Eight participants self-rated their driving skills as excellent and no one rated themselves as a dangerous driver. The ratings generated by their CATS driving scores found no excellent drivers and six dangerous drivers. Most novice drivers rated themselves between good and average or above, while their CATS rating indicate the majority demonstrated driving skills of average or below. No beginner driver received a dangerous rating based on their CATS driving score. The majority of experienced drivers were rated as average or above on both self-ratings and CATS ratings.

Table 3. Self-rating and Driving Test-rating by driver experience category

	Novice (0~2 years)	Beginner (3~5 years)	Experienced (6+ years)
Number of Subjects	20	21	9
Driver's Self Rating			
Excellent	1	4	3
Good	7	9	3
Average	8	5	2
Fair	0	3	1
Dangerous	4	0	0
CATS Driver Rating, DR (equation 3)			
Excellent	0	0	0
Good	9	11	4
Average	2	7	3
Fair	4	3	1
Dangerous	5	0	1

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5. DISCUSSION AND CONCLUSION

CATS offered novice drivers a platform to safely increase their driving skills through continuous virtual monitoring and testing. Several observations were noted during this study. First, novice drivers demonstrated greater potential in enhancing their driving skills and absorbing traffic rules than experienced drivers. Second, a relationship between the drivers' scores and their maximum / average velocity was observed: an increase in driving score correlates with a decrease in peak velocity, but an increase in average velocity. Third, a large proportion of drivers do not realize the potential risks created by driving over the speed limit. Finally, an average improvement of 28% in driving scores indicates that CATS succeeded in improving driver's simulated performance.

Driver Demographics. The case study participants were not teenaged drivers and these older novice drivers' experience may be different than those of the more typical younger novice and beginner driver seen in the United States. It appears many of the participants learned to drive after they arrived in the United States; less than half of the participants completed a formal driver training program in order to obtain their licenses. English was not the first language of any of the participants. In future studies, additional questions about their driving experience including miles driven and number of trips per week; the time of day most driving occurred; the general traffic and road conditions when driving should be considered to ensure the CATS system is designed to meet the participants' needs. Information about their driving warning, violation, and crash history should also be obtained. Furthermore, obtaining information about their experience using simulators or video driving games would also be helpful.

Driver Knowledge and Behavioral Intentions: The post-test scores indicated the case study subjects acquired new general driving knowledge. Confusion about what drivers should do when approaching flashing red or yellow lights appears in other studies involving South Carolina motorists (Alexander, Pidgeon, & Walters, 2008). Consideration should be given on how to highlight material from Chapter 7 "Traffic Signs, Signals and Markings" of the SC Driver License Manual (2013) more predominantly for all drivers in the state. Low seat belt usage rates in the home countries of the participants may partially explain the low pretest score about how to wear a seat belt correctly and the range of responses on the post-test statement regarding seat belt safety. The assessment tool needs refinement to become a valid and reliable instrument. For this case study, the 10-item test appeared adequate to demonstrate knowledge and behavioral intention could be assessed using the CATS system. Prior to incorporating the CATS system into a safe driving program, a valid and reliable assessment instrument should be developed.

Driving Performance, Driving Scores and Other Classification Factors: One aspect of the study evaluated the score improvements among novice versus beginner versus experienced drivers after using CATS. Overall, novice driver scores improved more than those of experienced drivers. It is not entirely clear whether the novice drivers improved their scores by learning and using the intended skills that the module addressed or whether they simply recalled the "trouble spots" on the track from previous practice laps because the course layout and tests did not change within the four fixed modules. Consideration should be given to developing randomized test modules for the CATS system. If during each lap, the driver met unexpected tests of their driving performance the results may more accurately reflect what skills they driver was learning.

It is harder for drivers to react properly to some situations when the vehicle is moving at a faster speed. A faster speed generally corresponds to a higher frequency of driving off the road or crossing double yellow lines when driving on a curvy road. The drivers who became more cautious on their second lap while driving on a curvy road demonstrated a better awareness of controlling vehicle speed under the limit compared to their first run. Overall, this illustrates drivers could improve their driving performance after achieving familiarity with the track and scenarios in the CATS system.

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In addition, consideration should be given to improvements in the CATS system to improve feedback to the driver while proceeding through the modules. For example, the force feedback driver for the G27 Logitech steering wheel was not used in this study. As the CATS system is developed for further use, several ways to correct this problem should be explored including (1) writing a driver to support force feedback in Linux or (2) transplant the CATS system from its current Linux platform to the Windows platform that the G27 supports.

Driver Ratings: Participants' self-confidence in their own driving ability, regardless of their experience, exceeded what was measured through the CATS driver rating. Consideration should be given to whether a module could be developed for the driving simulator to determine an actual baseline skill level prior to the training. In addition, a more realistic track that simulates the participants' actual driving environment would aid them in improving their skills by becoming more aware of actual road situations they frequently face. Code changes could be programmed into the track building stage to support a more realistic road environment. One such change to consider would be to support up to four artificial intelligence vehicles driving on the road, including at least one vehicle driving in the opposite direction to create more realistic traffic conditions.

Next Steps: Driving simulators have long been used to introduce fundamental driving skills and strategies to novice drivers. Today's young drivers are accustomed to video gaming and operating in a virtual environment. The personal computer-based portable Clemson Automotive Training System (CATS) was developed as a potential learning tool for use in a safe driving program while participants wait for in-vehicle practices. CATS includes a track with four module scenarios. It provided feedback to the driver immediately after completing the driving runs and that data allowed CATS to generate an overall driver rating. In this case study, 50 participants completed the virtual driving training that included a pre-test, four driving scenarios, and a post-test. Results indicate the drivers improved their knowledge, behavioral intention, and skill scores. Further development is needed to refine assessment tools as well as to improve the realism in track and traffic graphics before it is piloted with teens enrolled in a safe driving program.

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Nomenclature List

DR Driver rating
DS Driver score
DY Driver years
$\bar{K}_{ij}$ Driving factor metric score
Nk Number of driving faults
k=1: Number of times vehicle traveled off road
k=2: Number of times vehicle ventured across double yellow line
k=3: Number of times vehicle traveled faster than posted speed limit

$$V_{peak} = \frac{V_{p2} - V_{p1}}{V_{p1}}$$

Peak velocity improvement between 1st lap and 2nd lap

$$V_{ave} = \frac{\overline{V_2} - \overline{V_1}}{\overline{V_1}}$$

Average velocity improvement between 1st lap and 2nd lap

V1 One time velocity during the 1st lap (m/s)
V2 One time velocity during the 2nd lap (m/s)

V_{p1} Peak velocity during the 1st lap, (m/s)

V_{p2} Peak velocity during the 2nd lap, (m/s)

$$\overline{V_1} = \frac{1}{t}\int |V_1| dt$$

Average velocity during the 1st lap, (m/s)

$$\overline{V_2} = \frac{1}{t}\int |V_2| dt$$

Average velocity during the 2nd lap, (m/s)

GREEK SYMBOLS

αij Weighted score for each driving factor
β Penalty factor

δ_1 One time steering angle during the 1st lap, (deg)

δ_2 One time steering angle during the 2nd lap, (deg)

δ_{p1} The maximum steering angle during the 1st lap, (deg)

δ_{p2} The maximum steering angle during the 2nd lap, (deg)

$$\overline{\delta_1} = \frac{1}{t}\int |\delta_1| dt$$

Average steering angle on the 1st lap, (deg)

$$\overline{\delta_2} = \frac{1}{t}\int |\delta_2| dt$$

Average steering angle on the 2nd lap, (deg)

$$\delta_{ave} = \frac{\overline{\delta_2} - \overline{\delta_1}}{\overline{\delta_1}}$$

Average steering angle improvement between 1st lap and 2nd lap

$$\delta_{peak} = \frac{\delta_{p2} - \delta_{p1}}{\delta_{p1}}$$

Peak steering angle improvement between 1st lap and 2nd lap

SUBSCRIPTS

n Total number of modules
t Total time of driving on the lap, (sec)

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Appendix A: Scoring metrics for the four modules in the CATS

Module 1: "Traffic Control Device" (i=1)						
j	α1j	$\overline{k_{1j}}$				
		0	1	2	3	4
1	15	V>32km/h	24km/h<V≤32km/	16km/h<V≤24km/h	8km/h<V≤16km/h	V≤8km/h
2	5	na	na	L>3m	L<0m	0m≤L≤3m
3	5	$\int\|\delta\|dt$ >360°	270°< $\int\|\delta\|dt$ ≤360°	180°< $\int\|\delta\|dt$ ≤270°	90°< $\int\|\delta\|dt$ ≤180°	$\int\|\delta\|dt$ ≤90°
Module 2: "Lane Selection" (i=2)						
j	α2j	$\overline{k_{2j}}$				
		0	1	2	3	4
1	5	Vp >96km/h	80km/h< Vp ≤96km/ h	64km/h< Vp ≤80km/h	48km/h< Vp ≤64km/h	Vp ≤48 km/h
2	15	F=0	Na	na	na	F=1
3	5	$\int\|\delta\|dt$ >360°	270°< $\int\|\delta\|dt$ ≤360°	180°< $\int\|\delta\|dt$ ≤270°	90°< $\int\|\delta\|dt$ ≤180°	$\int\|\delta\|dt$ ≤90°
Module 3: "Panic Braking" (i=3)						
j	α3j	$\overline{k_{3j}}$				
		0	1	2	3	4
1	7	F=0	na	na	na	F=1
2	3	R>2.5sec	2.0sec<R≤2.5sec	1.5sec<R≤2.0sec	1.0sec<R≤1.5sec	R≤1.0sec
3	3	D>60m	45m<D≤60m	30m<D≤45m	21m<D≤30m	D≤21m
4	3	T>4.0sec	3.0sec<T≤4.0sec	2.5sec<T≤3.0sec	2.0sec<T≤2.5sec	T≤2.0sec
5	3	u>1.0m/s2	0.5m/s2<u≤1.0m/s2	0.3m/s2<u≤0.5m/s2	0.1m/s2<u≤0.3m/s2	u≤0.1m/s2
6	3	$\int\|\delta\|dt$ >360°	270°< $\int\|\delta\|dt$ ≤360°	180°< $\int\|\delta\|dt$ ≤270°	90°< $\int\|\delta\|dt$ ≤180°	$\int\|\delta\|dt$ ≤90°
7	3	0m	0m	L<0m	L>3m	0m≤L≤3m
Module 4: "Obstacle Avoidance" (i=4)						
j	α4j	$\overline{k_{4j}}$				
		0	1	2	3	4
1	5	V>80km/h	64km/h<V≤80km/h	48km/h<V≤64km/h	32km/h<V≤48km/h	V≤32km/h
2	15	na	na	L>3m	L<0m	0m≤V≤3m
3	5	$\int\|\delta\|dt$ >360°	270°< $\int\|\delta\|dt$ ≤360°	180°< $\int\|\delta\|dt$ ≤270°	90°< $\int\|\delta\|dt$ ≤180°	$\int\|\delta\|dt$ ≤90°

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Appendix B: CATS results for 50 human test subjects

Subject	Gender	Age	Driving Experience	Driving Score (DS)		Improvement (%)	Driver Rating (DR)
				1st Run	2nd Run		
1	M	25	3~5	46.5	75	28.5	Average
2	M	23	0~2	66.8	80.8	14	Good
3	M	25	0~2	35.2	81.5	46.3	Good
4	M	28	3~5	82	82	0	Good
5	F	23	0~2	73.8	75.5	1.8	Average
6	F	24	0~2	71.3	83.75	12.5	Good
7	F	24	0~2	45	44.5	-0.5	Dangerous
8	M	23	0~2	54.5	73.8	19.3	Average
9	F	26	5~10	74.3	67	-7.3	Fair
10	F	24	5~10	64.5	59	-5.5	Dangerous
11	M	22	5~10	36.3	85	48.8	Good
12	M	20	3~5	39.5	86	46.5	Good
13	M	23	5~10	1.8	77.5	75.8	Average
14	M	20	5~10	86.5	86.5	0	Good
15	M	24	3~5	63.8	77.5	13.8	Average
16	M	27	3~5	91.3	85	-6.3	Good
17	M	25	0~2	5	66.3	61.3	Fair
18	M	27	0~2	26.8	64	37.3	Fair
19	M	23	0~2	30	46.8	16.8	Dangerous
20	M	27	0~2	75.3	69	-6.3	Fair
21	M	26	0~2	47.8	85	37.3	Good
22	M	26	3~5	82.3	84	1.8	Good
23	M	25	3~5	64.3	60	-4.3	Fair
24	M	24	3~5	51.3	88	36.8	Good
25	F	25	3~5	83.8	87	3.3	Good
26	F	24	3~5	66	80.8	14.8	Good
27	F	27	3~5	78.3	66.3	-12	Fair
28	F	26	3~5	68	79.3	11.3	Average
29	M	23	0~2	42.5	54.5	12	Dangerous
30	F	26	0~2	50.5	48.8	-1.8	Dangerous
31	M	25	3~5	-1.3	83.3	84.5	Good
32	M	25	0~2	81.8	81.5	-0.3	Good
33	M	24	0~2	-26.3	50.8	77	Dangerous
34	F	24	3~5	85	88	3	Good
35	M	28	0~2	72.8	84.5	11.8	Good
36	M	24	0~2	65	87	22	Good
37	M	25	3~5	88.3	74	-14.3	Average
38	M	29	3~5	57.5	65	7.5	Fair
39	M	31	3~5	51.3	75	23.8	Average
40	F	27	0~2	74.3	83	8.8	Good

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Appendix B continued: CATS results for 50 human test subjects

Subject	Gender	Age	Driving Experience	Driving Score (DS)		Improvement (%)	Driver Rating (DR)
				1st Run	2nd Run		
41	F	27	0~2	62	85.8	23.8	Good
42	M	30	5~10	46.3	70	23.8	Average
43	F	25	3~5	72.8	75.3	2.5	Average
44	M	18	3~5	74.3	85	10.8	Good
45	M	32	5~10	50.8	78.8	28	Average
46	M	26	3~5	26.3	76.8	50.5	Average
47	M	26	3~5	72.5	83.3	10.8	Good
48	F	21	5~10	83.8	84.5	0.8	Good
49	M	26	5~10	82.5	80.8	-1.8	Good
50	M	22	0~2	63.8	60	-3.8	Fair
Average				57	75	28	Average

Appendix C: Driving simulator study detailed results

Subject	Improvement (%)					Improvement (number)		
	Driving Score	Vpeak	Vave	δpeak	δave	N1	N2	N3
1	28.5	-5.2	3	-5.2	10.9	0	-1	-3
2	14	-0.6	-0.4	-334.6	-3.3	0	-1	-3
3	46.3	-2.1	0.2	-77.1	34.3	-3	-1	-5
4	0	-0.6	3.3	228.5	8.2	0	0	1
5	1.8	-0.3	1	-268.8	-2.9	-1	0	1
6	12.5	0.2	-2.1	-346.2	-0.4	0	-2	-1
7	-0.5	-0.9	5.2	-279.7	-4.8	-2	-2	3
8	19.3	1	-4.4	-51.4	-8.9	1	-1	-3
9	-7.3	-2.2	2.7	-124.1	2.6	-1	0	2
10	-5.5	-2.8	9.2	-73	11	-1	0	0
11	48.8	-3.8	2.5	-334.6	-18.9	-1	-2	-5
12	46.5	-21.1	1.1	-387	1.3	-1	-3	-6
13	75.8	1.3	-1.7	-247.8	12.6	-1	-4	-6
14	0	-0.2	2.5	65.8	-1	0	0	0
15	13.8	-5.5	-3.2	-296	-7.6	1	-2	-2
16	-6.3	0.1	2	-87.2	-1.6	0	0	0
17	61.3	-10.9	-4.6	0	-14.1	-4	-3	-4
18	37.3	-0.5	0.5	-291.6	-23.1	1	-7	-2
19	16.8	0.5	-4.6	286	0.3	2	-1	-4

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Appendix C continued: Driving simulator study detailed results

Subject	Improvement (%)					Improvement (number)		
	Driving Score	Vpeak	Vave	δpeak	δave	N1	N2	N3
20	-6.3	-2.9	6.5	-108.6	7.3	0	-1	2
21	37.3	0.1	6.2	-353.4	-15.9	-2	-2	-2
22	1.8	-1.6	3.1	-71.9	10.1	1	0	0
23	-4.3	-1	1.3	263.4	-2.7	1	0	-1
24	36.8	-3.3	3.7	-90.7	4.7	-2	0	0
25	3.3	-0.9	7.8	5.6	-0.5	0	0	0
26	14.8	-2	0.1	-9.4	-2.6	-1	-2	0
27	-12	1	1.8	7.3	2	-1	0	-1
28	11.3	0.2	3.8	-96.2	0.5	0	-3	0
29	12	-1.5	2.7	-104.5	-0.8	-1	1	-3
30	-1.8	0.9	2.5	109.9	-3.9	2	-3	0
31	84.5	-10.5	-7	-378	-1.3	-3	-4	-9
32	-0.3	-0.7	1.1	-225	-18.9	0	0	0
33	77	-5.4	-0.7	-359.4	-14.5	-2	-2	-5
34	3	1.8	3.2	31.5	1.4	0	0	0
35	11.8	-0.9	1.2	3.1	-1.3	0	0	-2
36	22	-1.5	0.6	31.1	2.9	0	0	-1
37	-14.3	-0.7	1.8	-134.2	-0.7	2	0	1
38	7.5	4.5	2	-18.1	-0.3	0	0	-1
39	20.8	-0.4	-1.9	-322.4	-0.4	-1	-1	-2
40	8.8	-0.6	-1.3	10.2	-0.1	-1	-1	0
41	23.8	0.3	-3.6	-177.4	-1.5	-2	0	-3
42	23.8	-0.9	-1.3	-105.5	0.4	-1	0	-4
43	2.5	-1.9	2.6	185.9	1.5	1	0	-1
44	10.8	-0.1	2.4	15	1.6	-2	0	0
45	28	0.7	1.1	-334.5	18.2	-2	-2	-1
46	50.5	-4.7	-2.1	-213	-1.8	-4	0	-2
47	10.8	-1.7	2.2	-12.8	1.5	-1	0	-1
48	0.8	-1.6	9.4	6.6	4.8	0	0	0
49	-1.8	-1.7	4.8	65.5	12.9	1	0	0
50	-3.8	7.6	-1.5	-146.9	-1.9	1	0	-1
Average	17.2	-1.7	1.3	-103	-0.1	-0.5	-1	-1.5